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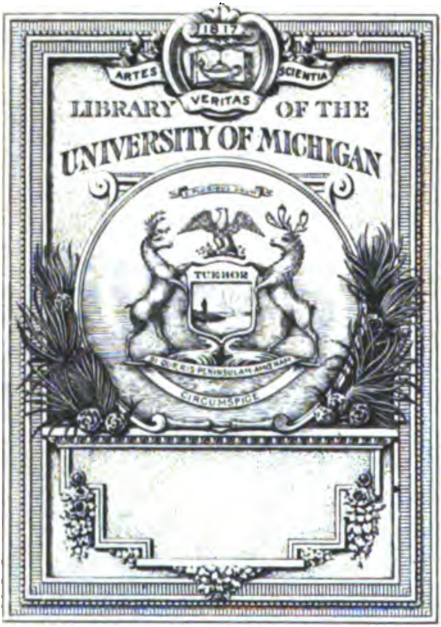

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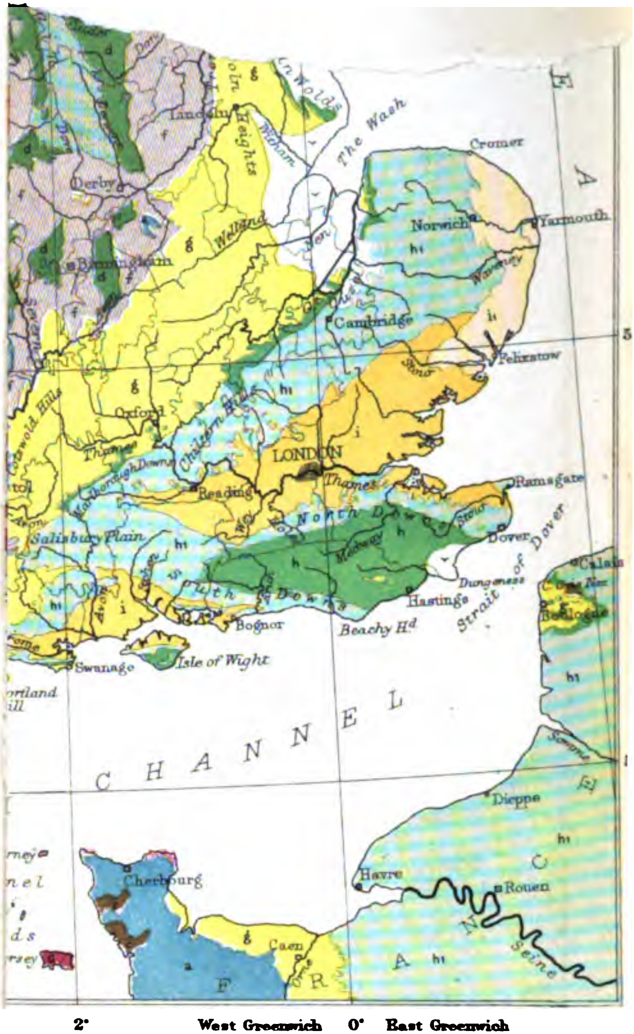
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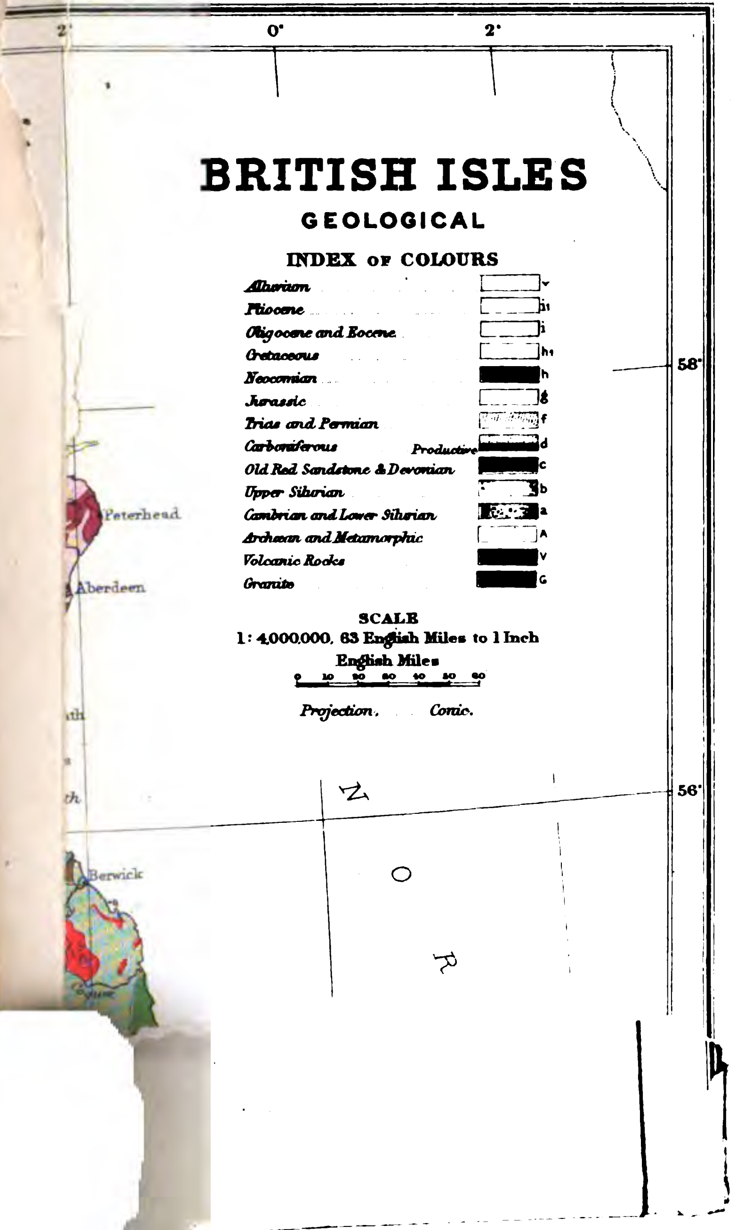

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GEOLOGY

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BY

CHARLES BIRD, B.A. LOND., F.G.S.

HEAD MASTER OF THE MATHEMATICAL SCHOOL, ROCHESTER

LONDON
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PREFACE

In the preparation of this volume the requirements of students studying the subject as laid down in the syllabus of the advanced stage of the Science and Art Department have been largely, but not exclusively, kept in view, and, in order to render the book as generally interesting and useful as possible, chapters have been inserted to illustrate the various points of contact which Geology has with practical life, including its application to such questions as water supply, agriculture, mining, and building material. Although the figures and, in some places, the text of the elementary volume have been largely drawn upon, a considerable number of illustrations have been added. Some of these are borrowed from other works published by Messrs. Longmans, especially Professor Green's "Physical Geology," and Mr. Bauerman's "Systematic Mineralogy," but the majority have been specially prepared. Perhaps the most noticeable, and to many the most interesting, are those from photographs of fossils, rocks, and minerals in the Jermyn Street Museum, for which I am indebted to the kindness of Mr. Rudler and his colleagues. Some of these are purposely taken from the identical specimens which have been employed in the illustration of monographs, in order that a comparison may be made of the two processes. The illustrations of rock scenery have, by permission, been prepared from a selection of the beautiful photographs published by Messrs. Wilson of Aberdeen.

It is, no doubt, needless to remark that lectures and books on Geology should be supplemented as much as possible by outdoor excursions and by visits to museums.

C. B.

ROCHESTER,
February, 1894.

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CHAPTER I.

HOW GEOLOGY SHOULD BE STUDIED, AND THE USES TO BE MADE OF IT.

THE word "geology" means a discourse or treatise on the earth, but in practice it is restricted in its application to the study of the outer shell, or "crust," of the earth and its contents. In connection with this study we examine the mineral and chemical composition of the materials of which the crust is composed, all of which are included under the name of "rocks," and endeavour to ascertain by what means and under what conditions they were originally formed, what changes they have undergone since the time of their formation, and what alterations they are undergoing at the present time. The question of the origin of rocks leads to the consideration of the astronomical position of the earth, and to speculations as to its former condition; and to the study of the various influences to which it has been and now is subjected. This leads to the investigation of all the different agents which are at work on and below the surface of the earth at the present time, some of which are occupied in building up new rocks, some in disintegrating and wearing away the old ones, and others in altering in various ways their texture, composition, and position. Any one even casually glancing at specimens of various rocks soon perceives, embedded in the stone and forming a part of it, the remains, more or less complete, of a great variety of animals and plants. These are called "fossils," and their study opens up questions of the deepest interest and importance in connection with the history of the development of life on the earth.

Geology, especially that part of it which concerns the rocks themselves, is essentially an out-of-door study. The rocks must be studied in their natural positions, as they are to be seen in sea cliffs, in ravines, and on hillsides, in mines, in well-sinkings and borings, in railway cuttings and quarries, and wherever they are exposed to view. Studying them in this manner, we soon perceive that very many of the rocks lie in horizontal or slightly inclined layers, sometimes thick and sometimes thin, one on the top of the other. Occasionally the layers are greatly inclined, and even bent and contorted, and sometimes broken and shattered; but still it is quite easy to make out the layers resting on each other, and further careful investigation soon leads us to conclude that these layers, or strata, were originally nearly or quite horizontal, and that they have been subsequently displaced.

We next notice that these stratified rocks differ much from one another in appearance, texture, and composition. A very common kind of rock is that which is made up of grains of sand cemented together. When such a rock is broken up with a hammer it is quite easy to perceive that it is nothing but ordinary sand generally mixed with some material which has caused the grains to adhere together. If a little dilute hydrochloric acid is poured on the crushed stone it may happen that effervescence takes place. This is caused by the escape of carbonic acid, and it may be taken as a proof that the cement consisted largely or wholly of carbonate of lime. When all action has ceased even when more acid is poured on, the insoluble residue may be separated from the liquid, washed, dried, and examined under a lens. It will be seen to be merely sand, perhaps with a little clayey material intermixed. The sand may be very fine-grained or coarse and angular, and will generally be found to consist of little pieces of quartz or silica, very much like the sand which may be seen on the sea-shore at present. By weighing the crushed stone at first, and afterwards the insoluble sand derived from it, the relative weights of the sand and the cementing material may be ascertained. It may happen that there is no visible action when the hydrochloric acid is added. In that case there is no carbonate of lime present. The liquid may be

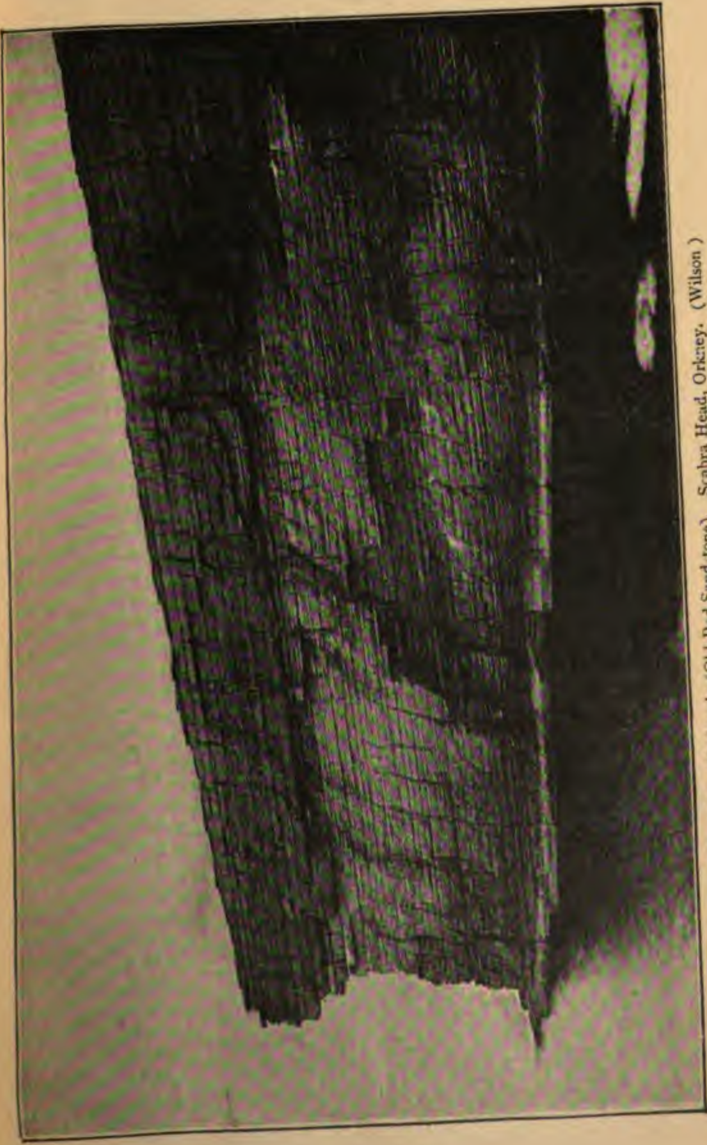

FIG. 1.—Stratified rocks (Old Red Sandstone). Scabra Head, Orkney. (Wilson.)

poured off after a time, and tested for the presence of iron, which will be recognized by its giving a deep blue colour when ferrocyanide of potash is added to the solution. If the crushed stone does not appear to lose weight after standing some time in the dilute acid the cementing material is in all probability silica, *i.e.* the same material as the grains of sand themselves. In that case it would probably have been observed that the stone was very hard and refractory. It may happen that the insoluble residue consists very largely of fine muddy material mixed with sand, constituting what we should call a muddy sandstone. In this way, by the help of a lens and a few simple chemical tests, much may be learnt about many rocks.

Another common rock often associated with sandstones is *shale*, a dark-coloured, fine-grained material, comparatively soft, with a tendency to split into thin layers. *Slate*, though harder and splitting in a different manner, is practically a rock of the same kind. It does not dissolve in acids, but when broken up and stirred in water it simply forms a dark mud or clay. Rocks of both the sandy and muddy classes frequently contain fossils. *Limestones*, which are found in many parts of the country, also constitute a common and very important group of rocks. When examined by a lens they do not as a rule appear to be composed of small particles like the preceding, but they consist of shells, whole and broken, mixed with, or scattered here and there in, a mass of hard compact stone, which may be any shade between white and black. When a piece is broken up and placed in dilute acid it effervesces and gradually dissolves, forming a more or less clear solution. If no residue remains we should say it was a pure limestone; if a perceptible quantity of sand remains it would be called a sandy limestone; if muddy material remains, a muddy or clayey limestone; and so on. If sand or clay predominate, the rock would be designated a calcareous sandstone, shale, or clay, as the case may be. Limestones will be found to differ much in hardness, some ringing under the hammer, and others, like chalk, being comparatively soft. They often contain some particular fossil in sufficient abundance to give them a special character and name; thus we have encrinital limestone, pentamerus limestone, coral limestone, etc.

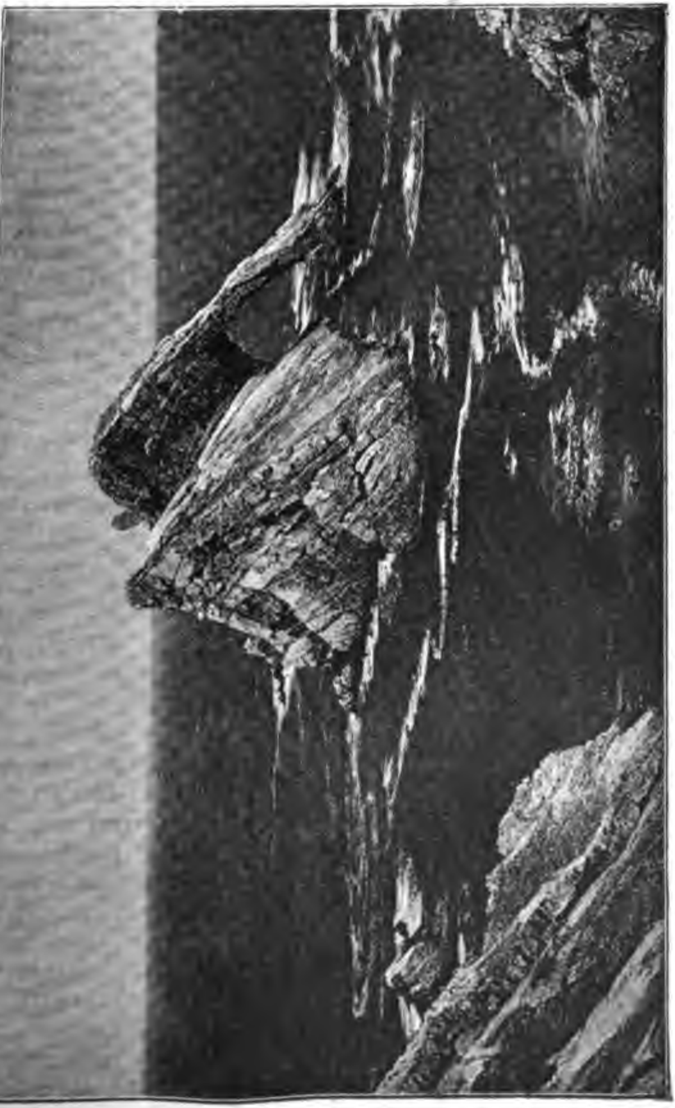

FIG. 2.—Inclined strata (Archæan). The "Bow and Fiddle Rock," Port Knockie, near Cullen, Banffshire. (Wilson.)

All the foregoing rocks are stratified, lying in thick or thin layers one on another. Sometimes layer upon layer of the same kind of rock make up a pile hundreds of feet thick, as is the case with the chalk, the mountain limestone, the "millstone grit," the Oxford clay, and many other masses to be afterwards described; while sometimes limestones and sandstones alternate with each other in close succession.

It may happen, however, that in the district examined none of these rocks may exist; but instead of them we may find rocks which do not lie in layers, or strata, at all, but in great masses, often cracked and shattered, but showing no trace of horizontal layers, or any tendency to split into layers either thick or thin. *Granite* is one of the best known, and a typical rock of this kind. As with the other rocks already described, there are many varieties of granite; but they all agree in consisting in the main of three different ingredients, which can be easily recognized by the naked eye. One of these three is felspar, which is generally either pink or white. It exists in more or less perfect crystals, soft enough to scratch with the point of a penknife, and sometimes two or three inches long, embedded in a very irregular fashion in hard, glassy-looking quartz. Scattered about among these two are specks and flakes of dark-looking mica. Granite breaks up with difficulty into rough irregular fragments, shows no tendency to dissolve in any of the ordinary acids, and is a very good example of a *crystalline* rock. Some other rocks of this kind, such as *basalt*, are of a close fine texture, and apparently, though not really, alike all through, but they all resemble granite in being unstratified, and they never contain fossils. There is every reason to believe that they were once molten, and they are hence called *igneous;* and as they often seem to have forced their way into and among the other rocks, they are sometimes called *eruptive.*

By studies of this kind we gradually make acquaintance with the various kinds of rocks which have built up the earth's crust; and by combining knowledge obtained in this way with observations on what is now happening on the earth before our eyes, we are able to form an idea of how the various rocks originated, and how they got into their present condition.

The various forces which are at work in this way are called *geological agents*, and will be fully considered hereafter. One of the most widespread and efficient is water, in the form of rain, rivers, and sea, or in its solid condition as snow and ice. Aided by wind, and by changes of temperature, it disintegrates the rocks, carries their broken-up or dissolved material down to the sea, forms banks of mud and sand, wears away the cliffs, and spreads out the broken-up material in thin layers on the beach. The more these actions are watched and thought over the more easy it seems to account for the existing rocks and the various appearances they present; and there seems to be little doubt that, at the far-off period when the various rocks were formed, the earth was in many respects very much like it is now. Just as at present we see the mud and sand of our shores pitted with raindrops, ridged up into ripple-like markings by the friction of the receding or incoming water, impressed with footprints of crabs and birds, or marked with the tracks

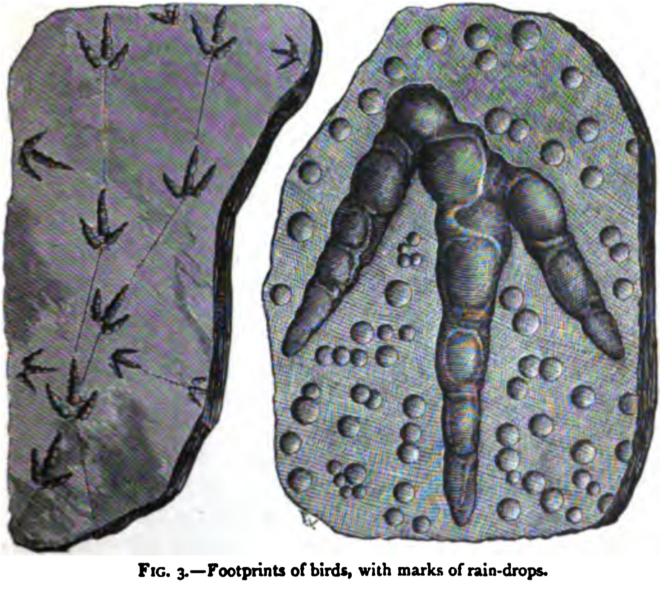

FIG. 3.—Footprints of birds, with marks of rain-drops.

and pierced with the burrows of worms, so we see all these markings in the surfaces of some of the layers of shale and sandstone when they are separated from one another, thus proving that in those times a sea-beach was very much like it is at present, and that the tides ebbed and flowed, and the rain fell, then as now.

The fossils which are embedded in the rocks place in our hands a means of studying the natural history of the periods at which the various rocks were formed. People must have noticed many of these fossils long ago, indeed they are mentioned incidentally by some of the ancient Greek and Latin writers; but so little was known of existing life that very few noticed that these fossils were different from the creatures then living. More extensive knowledge and study, however, gradually made it clear that very many of the rocks contain fossils which are totally unlike anything living on the earth in the present day. The study of fossils, called *Palæontology*, is intimately associated with geology, and, when combined with the study of the rocks themselves, enables us to some extent, in imagination, to restore the geography of the periods when the rocks were formed.

The science of geology, then, naturally divides itself into the study of the physical and chemical characters of the rocks and their contents, the study of the geological agents, and the history of past epochs as illustrated by their rocks and fossils.

Besides the great scientific interest of geological pursuits and studies, the subject has many points of contact with practical life. A few of these may be briefly alluded to here, though several will be more fully dwelt upon in special chapters.

Rock study gives a practical knowledge of the resources of a district as regards building materials, and will often prevent unnecessary labour and expense, such as has been incurred in past times in sending limestone for official buildings from Malta to Corfu, where there is plenty readily accessible; in sending granite from Aberdeen to Newfoundland, flagstones from Forfar to Nova Scotia, or lime from Plymouth to Bermuda. A case is also quoted of a Boer farmer, who had been for years in the habit of fetching, at great trouble and expense, limestone pebbles from a distance, till a casual traveller with some geological knowledge pointed out to him that the cliff behind his house consisted of the same material. Comparatively valueless minerals have often deceived the ignorant and led to unremunerative expenditure. Iron pyrites, copper pyrites, and mica have been mistaken for gold ore; and calcite, quartz, felspar, and other common minerals, have raised delusive hopes which a little knowledge of the properties of minerals would have spared.

In mining, ignorance of some of the common facts of geology has led to serious mistakes. For example, on the top of the rocks in which our English coal is found there lies a series of red sandstones and marls, some three or four thousand feet in total thickness. Where the lower of these are at the surface, a shaft sunk down will reach coal at a workable distance; but if sunk in the uppermost of the series it would be hopeless. Yet there are cases where this has been done at an expense of thousands of pounds. Below the coals there are other red rocks much older, and in some cases these also have been vainly penetrated by shafts, although a very little knowledge of fossils would have made the mistake evident. Mining engineers are, of course, quite aware of the importance of minute local geological knowledge, and few such mistakes are made at the present day.

Water-supply from deep wells is also an entirely geological question, depending on the character and lie of the rocks of the surrounding neighbourhood; and yet, even in the present day, we hear of the employment of the "divining rod" for the purpose of fixing the position of the proposed well!

The effect of percolating water upon various strata of the looser kind often causes catastrophes which a fuller knowledge of the conditions under which landslips occur might have averted. Serious damage is often sustained through mistakes of this kind, as at Sandgate lately, where a large mass of sandy strata saturated with water slipped down towards the sea, and damaged a large portion of the town. In a smaller degree also heavy buildings often suffer from insufficient foundations on unstable ground, as in the case of the Sheerness forts; and much trouble and occasional accidents are caused by the slipping of the sides of railway cuttings through such strata, as for example on the line between Brokenhurst and Christchurch.

In many books of travel the descriptions of scenery would be much more intelligible and interesting if the traveller had been acquainted with geological science sufficiently to understand the way in which the shape of the surface of a country depends upon the nature of the rocky materials of which it is composed.

Enough has, however, been said to show that, in addition to its theoretical and intellectual bearings, the study of geology should be an important part of the technical education of all those who are to be concerned in the utilization of the inorganic products of the earth, either as travellers and explorers, builders, miners, or engineers.

SUMMARY.—1. Geology is that branch of science which is concerned in the study of (*a*) the earth's crust; (*b*) the various forces which build up, alter, or destroy the rocks; (*c*) the history of the various changes the earth has undergone as far as it can be obtained from the study of the rocks and the fossils they contain.

2. We should study geology as much as possible out-of-doors, observing that (*a*) some rocks are stratified and fossiliferous, and others not; (*b*) they differ much in texture and composition, as may be seen by examining, optically and chemically, such rocks as sandstone, limestone, shale, granite, basalt; (*c*) many agents are at work upon the earth's crust, bringing about geological changes, the chief among them being water; and that these agents seem sufficient to account for nearly everything we observe in the rocks.

3. Fossils, only understood and appreciated in modern times, supply us with a history, somewhat incomplete, of life on the earth.

4. The study of geology is of practical value in connection with the supply of building materials, mining, water-supply, and various engineering works.

QUESTIONS.

1. Define *geology*, and distinguish it from *geography*.
2. Describe the general appearance (*a*) of a lofty cliff composed of stratified rocks; (*b*) of a granite quarry.

3. In what ways can a specimen of rock be readily examined? Describe what would be learnt from the examination of a piece of (*a*) sandstone, (*b*) granite.

4. What evidence is there in the rocks to prove that some of them were laid down on a sea-beach?

5. Explain in what way a practical knowledge of geology would be useful to a settler in a new country. Illustrate also its value in coal-mining.

CHAPTER II.

MINERALS (1).

A VERY important branch of geology is that which is concerned with the composition and character of the various materials of which the solid crust of the earth is composed. The study of the materials as we see them in large masses in quarries, cliffs, and mines is called *petrology*, while the more minute study of small specimens of the rocks, which can be carried on indoors, is called *lithology*. By means of this latter study we learn that rocks are not as a rule homogeneous or alike throughout, but that they are composed of two or more different materials. Just as a brick wall can be seen to be composed of bricks and the mortar which fixes them together, so, for instance, can many specimens of sandstone be seen to be made up of rounded grains of clear quartz or flint and a kind of mortar or cement which causes the grains to adhere together. The method by which the composition of a sandstone may be ascertained has already been described. The constituents of a rock which can be easily separated in this manner are called *minerals*. Minerals, as a rule, have a more or less definite chemical composition, which can be expressed by a formula; and they have, like other chemical compounds, their special properties. The rock, on the other hand, may vary very much as to the relative proportion of its constituent minerals. In the case given above, of a calcareous sandstone, the amounts of quartz and carbonate of lime respectively may vary to any extent.

Common granite is an example of a rock built up of three constituent minerals, all of which can be very easily observed with the naked eye. The felspar, mica, and quartz are all definite chemical compounds; while the granite may contain them mixed in almost any proportion, or may even have one of them replaced by some other mineral, and still be considered granite.

Other rocks have their mineral ingredients more intimately mixed together, so that they cannot be distinguished without microscopic examination. Such a rock is basalt, which is a dark-coloured, close-grained rock composed of a fine mixture of *felspar* and another mineral called *augite.*

As, therefore, minerals are the materials of which rocks are built up, the study of minerals, or "mineralogy," is an important branch of geology, and some acquaintance with it is necessary before the rocks can be properly studied and understood. Fortunately, however, the minerals which are largely concerned in rock-making are comparatively few in number. The less common ones are sometimes present as rock constituents, but they more commonly occur as deposits in lodes, veins, and cavities. These latter, though of comparatively small importance from the geological point of view, are both important and interesting industrially, as they furnish us with most of our metallic ores and with our precious stones.

The study of minerals is of considerable antiquity. Theophrastus, who wrote on the subject two thousand years ago, classifies them as metals, stones, and earths. He enumerates the more common properties of stones which could be used in discriminating them, such as colour, transparency, brightness, density, hardness, tenacity, together with other more remarkable and less common properties, such as the attractive quality of amber. He also describes the various purposes for which different stones were suitable, as for engraving, turning, carving, etc. The less obvious but more scientifically important properties were, however, for a long time unnoticed.

The transparent, ice-like appearance of quartz and its geometrical shape were, however, noticed at an early date, and obtained for it the name of "crystal," from the Greek word for "ice." Nothing was known of chemical composition at this time, and the explanation of the crystalline appearance presented by this mineral was that it was formed from water by the action of intense cold, an idea which, like many other equally erroneous notions of the classical writers, maintained its supremacy till within two centuries ago. This particular error was carefully refuted by Robert Boyle. The term *crystal* was afterwards extended to other minerals which possess a geometrical shape, whether transparent or not, the original crystal being then called *rock crystal*, a name which it still retains.

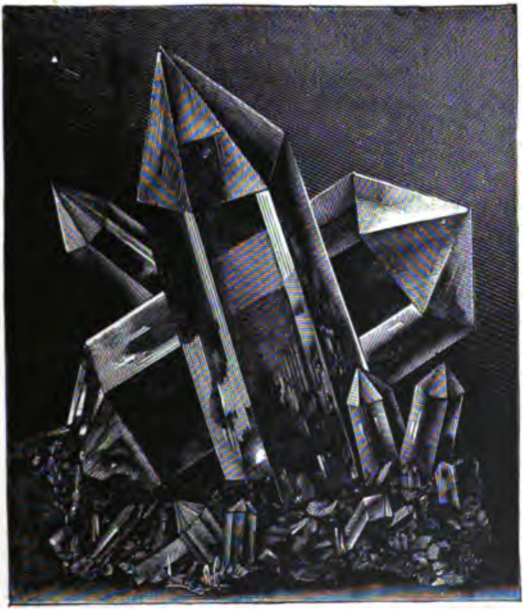

FIG. 4.—Crystals of Quartz (rock-crystals). The lines on the crystals only indicate shading.

The first serious study of the crystalline forms of minerals was made by **Steno**, a Danish physician, who pointed out that different specimens of rock crystal, though differing in size and shape, yet resemble each other in having their sides inclined to each other at the same angle, and he offered suggestions as to the way in which the crystals were built up. A hundred years later, artificial crystals were studied and compared with natural crystals; and **Romé de l'Isle**, after an extensive examination of all the crystals of each kind which he could obtain, pointed out that, although there is an enormous variety of shapes, yet they can all be referred to simple primitive forms or models, including such geometrical forms as the cube, octahedron, tetrahedron, rhombohedron, hexagonal pyramid, etc. Taking each of these primitive forms, he explained how they could be modified and extended so as to form the other more complex shapes. The general principle which he put forward was briefly as follows: Taking the cube as the simplest crystalline model, he pointed out that the straight edges of the cube, which are formed by the junction of two of its sides, are liable to be cut off by flat surfaces. One of these flat surfaces may make equal angles with each of the two sides which form the cut-off edge. If so, the other edges will be cut off in the same way. On the other hand, the new surface may be more inclined to one side than the other. If so, another surface will be developed, similarly inclined to the second side. If one edge is in this way replaced by two new surfaces, each of the other similar edges is similarly replaced. Again, one of the eight solid angles of the cube may be cut off by one or more planes, and, if so, then all the other angles are similarly

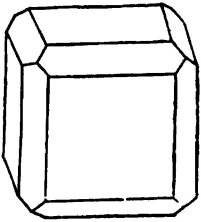

Fig. 5.—Edges cut off by one surface equally inclined to each side.

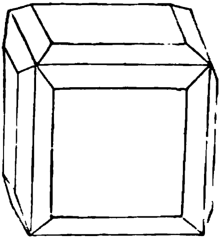

Fig. 6.—Edges cut off by two surfaces unequally inclined to each side.

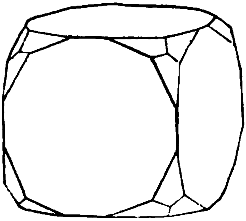

Fig. 7.—A cube with the solid angles modified.

modified. These secondary planes may be very small, and may thus still leave the crystal with a general cubical form; but they may be large enough to completely change the cubical shape. The cube with six square sides and eight solid angles may in this way, by the increase in size of planes which cut off the solid angles, be converted into a regular octahedron, with eight sides and six solid angles. Nevertheless, the octahedron, being derived from the cube, belongs to the same system, and any mineral substance, such as fluor-spar or galena, which generally crystallizes in cubes, may also form regular octahedra. The octahedron, in its turn, may have its angles and edges modified, and so give rise to new forms.

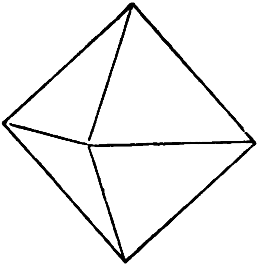

FIG. 8.—A regular octahedron.

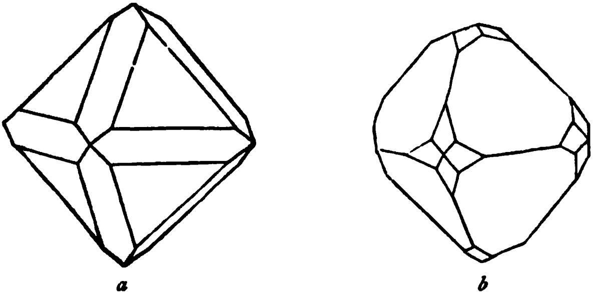

FIG. 9.—Modified octahedra. *a*, angles; *b*, edges.

The crystalline forms of calcite present another interesting illustration of De l'Isle's theory. The primitive form is the rhombohedron, a six-sided solid, which, like the cube, has all its sides equal, but, unlike the cube, its angles are not right angles. It has eight corners, or solid angles: two of them (A) are alike in being formed by the meeting of three sides all inclined to each other at the same angle, which may be denoted by *a*; the other six angles (B) are unlike the first two, but are similar to each other, inasmuch as they are contained by sides, two pairs of which are inclined to each other at angles which may be denoted by *b*, while the other pair are inclined at the angle *a*. The rhombohedron has twelve edges, each formed by the junction of two sides; but in the case of six of the edges the sides are inclined at the angle *a*, while the sides of the other six are inclined at the angle *b*. This distinction between the two kinds of angles and the two kinds of edges is important, because modifications only affect those angles and those edges which are similar. For instance, if a plane cuts off one of the two angles A in a certain manner, the other angle A is cut off in the same manner, but the other six angles are unaffected. On the other hand, if one of the set of six angles B is modified, each of the other five is also modified in the same way, but the two others are unaltered. Similarly with the edges. The modifications may consist of a plane cutting off the angles or edges in such a way as to be equally inclined to each side; or there may be, in the case of the edges, two, and, in the case of the solid angles, several, planes, the general principle being that each similarly situated side must be modified in exactly the same manner as the others. In this way the original rhombohedron may be converted into a regular six-sided prism, or into a double pyramid. That this geometrical principle is connected with some natural law is proved by the fact that calcite assumes these various forms.

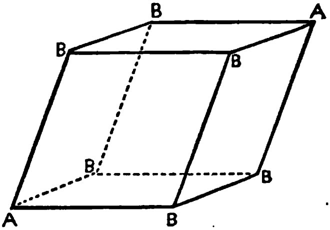

FIG. 10.—A rhombohedron, showing the two sets of solid angles.

These generalizations by Romé de l'Isle raised crystallography to the rank of a science, and aroused a general interest in the subject, which led to further developments.

So far no attempt had been made to explain the cause underlying these observed facts, but later investigators of the subject attempted various explanations. **Haüy**, for example, was the first to notice that many crystals, notably calcite, can have thin layers split off their faces or across their angles, and can be thus reduced to a simple primitive form; and he thence inferred that a crystal is really built up of a number of almost infinitely small primitive particles arranged in a symmetrical manner. The variations of form, however, are so great and complex that it is impossible to apply this principle to the explanation of all cases.

The recognition of the primitive form of the crystal is made still more difficult by the fact that all its angles or edges, though modified in the same manner, are not cut off to the same extent, the cases of perfectly symmetrical development of a derived crystalline form being quite the exception. Moreover, there are crystalline forms (*hemihedral*) which are derived from other forms by the suppression of alternate faces. Such is the case of the tetrahedron, which is developed from the octahedron in this manner. Again, it frequently happens that a crystal is "twinned," that is, formed apparently by the outgrowth of two similar crystals from a medial line; and further, a crystal often presents a crystalline form on one aspect only, the other being attached to the wall of the cavity or embedded in the general crystalline mass. It must also be remembered that crystals are formed and preserved only under specially favourable circumstances, when the whole cavity is not completely filled with mineral matter. If it is filled, the crystals grow together and form a solid mass which, though crystalline as regards its texture, does not show the form of the separate crystals.

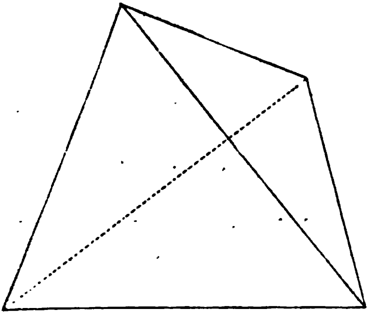

FIG. 11.—A tetrahedron.

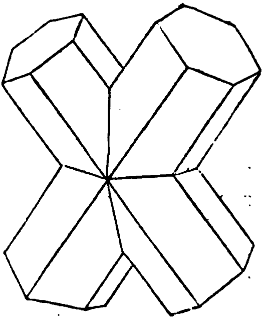

FIG 12.—Twins.

Closely connected with the crystalline form are the optical properties. These were first thoroughly investigated by **Sir David Brewster**, who, in 1819, pointed out that all crystalline forms can be grouped into three divisions by observing their action on a ray of polarized light, a method of research which owed its origin to the experiments and discoveries of **Malus**. The first division comprises, among others, the cube and the regular octahedron, and forms based upon them. These crystals have no effect at all on a ray of polarized light, in whatever direction it is passed through them. The second division, which includes the rhombohedron and six-sided prism, will only allow a ray of polarized light to pass through them in one direction without modification, while in the remaining group there are two directions in which a polarized ray can pass through unaltered. These properties can be studied by passing a beam of polarized light through slices of the crystals when under the microscope; and the discovery of these properties has added an important and interesting method of detecting the crystalline minerals which occur in rocks of a complex character.

From the consideration of their geometrical and optical properties, all the vast variety of crystals have been arranged into six groups, or "systems." All geometrical solids have imaginary lines, called *axes*, intersecting them. These axes cross each other at a certain point within the crystal, and each axis terminates on the surface at similar and opposite angles, or edges, or faces. They thus form the skeleton upon which the crystal is as it were supported, and their relative lengths and inclination to each other give its special character to each of the crystalline systems. These systems are as follows :—

1. *The Cubical system.* The crystals of this system have three axes, all equal, and at right angles to each other. The crystals are therefore, as a rule, very symmetrical and easily recognized. The simplest forms are the cube with six sides, the octahedron with eight, and the dodecahedron with twelve. There are also twenty-four- and forty-eight-sided crystals. The most common minerals of this system are fluor-spar, galena, blende, pyrites, diamond, and garnet.

2. *The Tetragonal system.* This system has three axes at

right angles, but one of them is longer than the other two. The tetragonal pyramid and prism are common forms, and copper pyrites and tin stone examples.

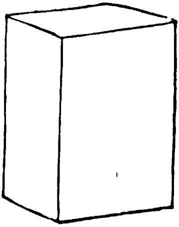

FIG. 13.—Tetragonal prism.

3. *The Hexagonal system.* In this system there are three equal axes in the same plane, intersecting at angles of 60°, and another axis at right angles to them. The hexagonal pyramid and prism and the rhombohedron belong to this system, illustrations of which occur in calcite, tourmaline, and calamine.

4. *The Rhombic system.* Here we have three axes, all unequal, intersecting at right angles, giving us the right rhombic pyramid and prism, and right rectangular pyramid and prism. Examples are found in aragonite, barytes, topaz, sulphur.

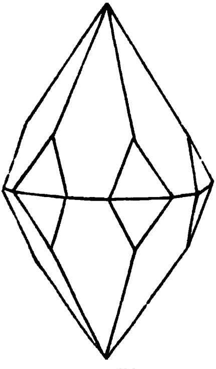

FIG. 14.—A modified double hexagonal pyramid.

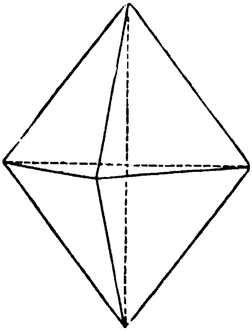

FIG. 15.—A double right rectangular pyramid.

5. *The Oblique system.* This system has three axes of unequal lengths, two at right angles, and the other oblique to them, forming the oblique rectangular pyramid and prism, and the oblique rhombic pyramid and prism. Examples are, augite, hornblende, orthoclase, felspar, gypsum.

6. *The Doubly-oblique system.* Here there are three axes, all unequal, and all oblique to each other, forming the doubly-

oblique rectangular pyramid and prism, and the doubly-oblique rhombic pyramid and prism. Albite and labradorite are examples.

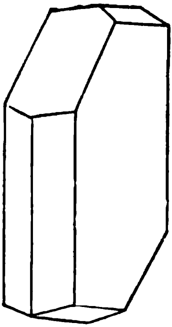

FIG. 16 —Rectangular prism, modified.

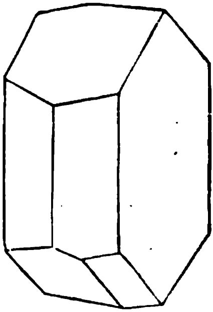

FIG. 17.—Double oblique rectangular prism, modified.

Crystalline form is the most striking characteristic of minerals, and that by which many of them are readily detected. but they differ from each other in many other ways. In describing a mineral it is usual to give its degree of *hardness.* For this purpose the hardness of one of the softest minerals, talc, is taken as 1, and that of the hardest of all, the diamond, as 10. The typical minerals which constitute the scale of hardness are—

1. Talc.
2. Selenite.
3. Calcite.
4. Fluor.
5. Apatite.
6. Orthoclase.
7. Rock-crystal.
8. Topaz.
9. Ruby.
10. Diamond.

The hardness of any given mineral would be determined by trying to scratch it with a sharp corner of one of the above. If, for example, it could be scratched by rock-crystal, but not by orthoclase, its hardness would be about 6·5.

The *specific gravity* of a mineral is another consideration. Meerschaum, at one end of the scale, is light enough to float in water with a specific gravity of about ·9, while heavy spar is

4·8, and galena 7·5. The specific gravity of a mineral can, as a rule, be readily obtained by weighing it first in the ordinary way, and then by hanging it in water by a thin thread and weighing it again. The loss of weight in the second weighing divided into the weight of the mineral in air will give the specific gravity.

The *colours* of minerals are often very distinctive and sometimes very beautiful. They are, however, not as a rule due to the actual mineral, but to the presence of a very small quantity of some impurity. The effect of a very small portion of a foreign substance in imparting colour is illustrated in the manufacture of coloured glass, where all the beautiful tints to be seen in our church windows are due to the addition of various mineral ingredients to the original colourless glass; and students of chemistry know very well what a number of beautiful tints may in the same way be imparted to a colourless and transparent borax bead.

It has been already stated that minerals are not *mixtures* like rocks, but *chemical compounds* having a definite composition. It should, however, be noted that different specimens of some of the more complex minerals vary considerably in composition, and it is not always easy to say whether some of the elements present are to be considered essential parts of the mineral, or are mere accidental additions. As, however, it will be convenient to consider the minerals in detail from the point of view of their chemical composition, the consideration of this character is reserved for the next chapter.

SUMMARY.—1. *Minerals* are definite chemical compounds with fixed physical and chemical properties; *rocks* are generally aggregates of two or more minerals.

2. The ancients were acquainted with the obvious properties of the common minerals, but knew nothing about their crystalline form or chemical composition.

3. Crystallography was first studied by Steno, and greatly advanced by Romé de l'Isle and Haüy; while, later, Brewster investigated the optical properties of crystals.

4. The crystalline systems are—

I. Cubical,	example	fluor-spar.
II. Tetragonal,	„	copper pyrites.

III. Hexagonal, example calcite.
IV. Rhombic, „ sulphur.
V. Oblique, „ gypsum.
VI. Doubly-oblique, „ labradorite.

5. The hardness and specific gravity are important aids in recognizing minerals; while, in some, the colours are distinctive.

QUESTIONS.

1. Explain the difference between *petrology*, *lithology*, and *mineralogy*.
2. Compare ancient and modern knowledge of minerals. What advances were made in the science by Steno, De l'Isle, Haüy, and Brewster respectively?
3. Explain how a simple geometrical solid may be modified so as to assume another form. What is meant by *primitive form*, *hemihedral*, *twinning?*
5. Explain how the hardness of a mineral specimen would be determined.
6. Upon what general principle are crystals classified?
7. How are many of the beautiful colours of crystals to be accounted for? Why are some specimens of fluor purple and others green?

CHAPTER III.

MINERALS (2).

ALL terrestrial compounds are built up of two or more of the sixty-four elements. Many of these elements are, however, very rare, and others are not at all common; and thus it happens that nearly all our common and important minerals are really composed of a very limited number of elements, some two dozen at the most. Minerals differ very greatly in composition. Some, such as the diamond, consist of one element only; others of two elements. In the latter case, one element is often a metal, and the other not: as, for instance, *pyrites*, a compound of iron and sulphur; *fluor*, a compound of calcium and fluorine. They may, however, both be non-metals, as in the case of *silica*, which consists of silicon and oxygen. By far the greater number of minerals, however, consist of at least three elements, and form a class of bodies known to the chemist as "salts." The simplest salts may be regarded as formed by the union of the oxide of a metal with the oxide of a non-metal; as, for instance, *calcite*, which is chemically a salt known as calcium carbonate, or carbonate of lime, and which, when made red-hot, separates into carbonic acid, an oxide of carbon which escapes into the air, and lime, or oxide of calcium, which is left behind. It may happen, however, that, combined with the one non-metallic oxide, there are two or even more metallic bases. This is particularly the case with those salts whose non-metallic oxide is silica, and for this reason those compounds are complicated, numerous, and varied.

A few elements preponderate very greatly in the earth's crust; notably oxygen, which exists in nearly everything. It has been estimated that within sixty miles of the earth's surface the percentages are as follows:—

Oxygen	50	Sodium	2
Silicon	25	Potassium	1½
Aluminium	10	The rest	3½
Calcium	4½		
Magnesium	3½		100

In the following enumeration the minerals are classified according to the above principle, and those which are of importance in rock-forming are distinguished by an asterisk. The Roman numeral, when given, denotes the crystalline system to which the mineral belongs, and the two other numbers which follow denote the average hardness and specific gravity respectively.

1. **Native elements.** These are mostly metals, and are not as a rule crystalline.

Copper. Native copper was known in prehistoric times, and was employed in making bronze for weapons and implements. It takes its name from the island of Cyprus; but the largest quantity of late years has been obtained from the neighbourhood of Lake Superior, where some thirty years ago a mass weighing four hundred tons was obtained. It is often found in irregular ramifications.

Silver. Large masses have been got from the Norwegian mines, and fibrous and dendritic growths are common in South America and other localities.

Gold. Gold is generally found either in quartz veins in the older rocks, or in alluvial material derived from them. In the latter case the particles and nuggets are water-worn, but sometimes show crystalline structure.

Some of the other metals are found occasionally uncombined; but, except platinum, not in quantities of either geological or commercial importance.

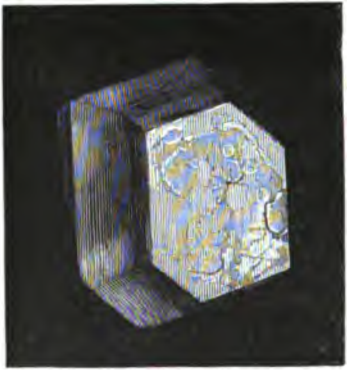
Fig. 18.—Sulphur.

Sulphur is often found in volcanic regions in the form of beautiful pyramidal crystals; no doubt formed by sublimation or by the decomposition of sulphides.

Carbon occurs native in two forms, as diamond and graphite. The former crystallizes after the cubic system (I.), and is very hard (10); the latter forms hexagonal crystals (III.), and is very soft (2).' Black diamonds are found in Brazil, and are used for drills. Graphite used to be obtained largely from Borrowdale, in the Lake Country, but is now chiefly got from Ceylon. It may be looked upon as the final stage in the metamorphism of vegetable matter, all the other chemical elements having been removed. In some cases, however, it may have been formed by igneous action, as small crystals of graphite are often found in furnace slag.

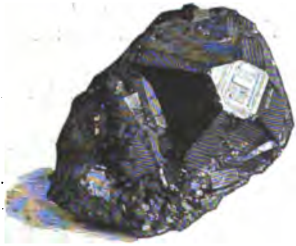
Fig. 19.—Galena, octohedral crystal.

2. **Sulphides**, or compounds of the metals with sulphur.

Blende, or zinc sulphide (I., 3·8, 4). This is a dark and nearly opaque mineral, brittle, and with a good cleavage. It occurs under the same circumstances as gelena, and is often associated with it.

Galena, or lead sulphide (I., 2·7, 7·5). It occurs in cubical crystals, single or clustered, often in massive aggregates, or in veins in limestone strata. It is especially abundant in the mountain limestone of Derbyshire, Yorkshire, and Cumberland.

Copper glance, copper sulphide; a Cornish ore.

Cinnabar, mercury sulphide; a dark-red mineral of the same composition as vermilion, an artificial product. It is the chief ore of mercury, and is found at Almaden, in Spain; New Almaden, in California; and in Austria.

Pyrites, or iron sulphide (I., 6·3, 4·9). This is a common and widely spread mineral, but of no industrial value as a source of iron, on account of the difficulty of getting rid of the last traces of sulphur. It is, however, employed as a source of sulphur in the manufacture of vitriol or sulphuric acid, and is also converted into ferrous sulphate, or "green vitriol." Nodules of pyrites are common in clays; and fossils embedded in clay are frequently changed into pyrites by a process of chemical displacement, the carbonate of lime or other matter of the fossil being replaced, particle by particle, by pyrites. This is particularly the case with the ammonites in the Lias, and the vegetable fossils of the London Clay. There is another mineral of the same composition, but of different crystalline form, called *marcasite*.

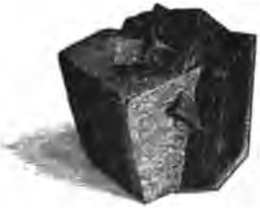

FIG. 20.—Iron pyrites.

Realgar and *Orpiment* are sulphides of arsenic.

Stibnite is an antimony sulphide.

Mispickel is a sulphide of arsenic and iron, and is the chief source of the arsenic compounds.

Copper pyrites is a double sulphide of copper and iron. It is used for the preparation of copper sulphate, or "blue vitriol."

3. **Chlorides.**

Rock-salt, or sodium chloride (I., 2·5, 2·1). Beautiful cubical crystals occur, but most of it is in thick lenticular masses among the rocks. It readily dissolves, giving origin to brine springs, and deliquesces in moist air. No doubt most of the deposits have originated by the gradual evaporation of sea-water in lagoons or salt lakes. The most noted and largest deposit worked is that at Wieliczka, in Austria, where houses, stables, and churches are carved out of the solid salt down in a deep mine. There are large beds extensively worked in Cheshire.

Sal-ammoniac, or ammonium chloride, is also met with occasionally as an incrustation of the soil, and in volcanic fissures.

4. **Fluoride.**

Fluor-spar, or calcium fluoride (I., 4, 3·2). This mineral is found in beautiful and variously coloured cubical crystals. In Derbyshire it is common, and is known as "Blue John." It is manufactured into ornaments, but its ready cleavage makes it very brittle. It is also found in the massive condition and in veins. Hydrofluoric acid is prepared from it.

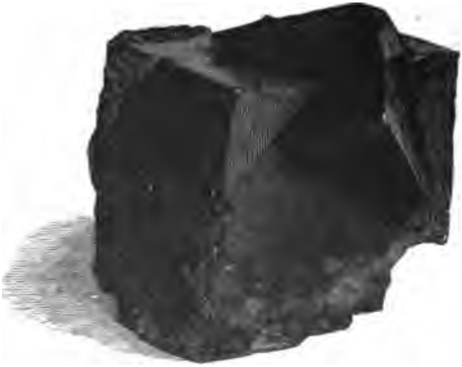

FIG. 21.—Fluor-spar.

5. **Oxides.**

Cuprite, or ruby copper; copper oxide. This mineral is an important ore of copper, and is often found in splendid ruby-coloured crystals. When melted with glass it gives it a fine red colour.

Spinel is a compound of magnesia, aluminium, and oxygen. Some of its transparent tinted varieties are used in jewellery, especially for watches, but they are deficient in hardness (8) for this purpose.

Magnetite, the magnetic oxide of iron, Fe_3O_4 (I., 6, 5). This is the richest of all the iron ores. It is found crystalline, but is generally massive. It derives its name from the fact that it is frequently magnetic, and is the ore from which the lodestone, or natural magnet, is derived.

Hæmatite is another oxide of iron, having the chemical composition of Fe_2O_3 (sesquioxide) (III., 6, 5). It is found both crystalline and massive: in the latter state it forms thick beds in Cleveland and Cumberland; while the crystallized form, known as *specular iron*, is found in Elba. In an earthy condition it is known as *red ochre*. It also occurs in certain gneisses and schists as an essential constituent. Hæmatite is often found allied with the sesquioxide of titanium, when it is known as *titaniferous iron*.

Corundum, a sesquioxide of aluminium (Al_2O_3). This is an exceedingly hard mineral (9), and as it is frequently found as transparent crystals, tinted by various minerals, it supplies us with an extensive series of precious stones. Its red variety is the *ruby;* blue, the *sapphire;* while other tints give very hard varieties of the *emerald*, *topaz*, and *amethyst*. The earthy condition of this mineral is *emery*, a well-known polishing material.

Pyrolusite, an oxide of manganese (MnO_2, manganese dioxide). This is the chief manganese ore, and the starting-point of most of the artificially prepared manganese compounds. It frequently occurs in dendritic, or tree-like, growths, between layers of limestone, and is not uncommonly mistaken for a fossil plant.

Tinstone, or *cassiterite*, is a dioxide of tin, and is the common tin ore of Cornwall.

* *Quartz* (III., 7, 2·7). This is perhaps at the same time the best known and the most important of all minerals. It occurs in magnificent transparent crystals in veins and cavities, it forms of itself entire beds of rock, and it is a constituent in most of the igneous and very many of the aqueous rocks. It is an oxide of the non-metal silicon (SiO_2), and bears the chemical name of silica. It obtained the name of "rock crystal" from its resemblance to transparent ice; and in that form, under the name of Brazilian pebble, is now much used for making spectacle and other lenses, on account of its hardness and consequent exemption from scratches. Silica occurs under many forms. As *flint* and *chert* it forms amorphous, concretionary, and nodular masses in chalk and limestone, while many of the coloured crystalline forms constitute well-

known precious and ornamental stones, such as *cairngorm*, *opal*, *agate*, *chalcedony*, and *jasper*. A hard splintery siliceous shale is known as Lydian stone. Flints and chert are, no doubt, formed by the solution and redeposition of organic siliceous shells, sponge spicules, etc.; vein quartz, agate, and the numerous deposits of crystalline and amorphous quartz have been formed by deposition from aqueous solution; while the quartz of the igneous rocks has been formed mainly by igneous plutonic action, aided, probably, by heated water or steam.

6. **Oxygen Salts.** These compounds contain at least three elements, oxygen being one, a non-metal such as carbon, sulphur, phosphorus, or silicon, being the second, and a metal the third. They are often regarded, as has been already explained, as formed by the union of a metallic and a non-metallic oxide.

(1) *Carbonates.* These, on the above principle, may be regarded as formed of a metallic oxide, and the oxide of carbon known as carbon dioxide or carbonic acid. The chief carbonate, from the geological point of view, is—

* *Calcite*, or carbonate of calcium (III., 3, 27). This is a very common and important mineral. It is found crystallized in a great many forms, all belonging to the hexagonal system. The rhombohedral form is often very clear and transparent, and is known as *Iceland spar*. It cleaves very easily, and exhibits the phenomenon of double refraction. Another common form is known as *dog's tooth spar*: a fibrous variety, with a satiny lustre, is called *satin spar*, though this term is also applied to a variety of calcium sulphate. The *stalactite* and *stalagmite* on the roofs and floors of limestone caves, and *travertine*, deposited from springs, are other forms. It is also found in the massive condition as limestone rock. At a red heat in the fire, or under

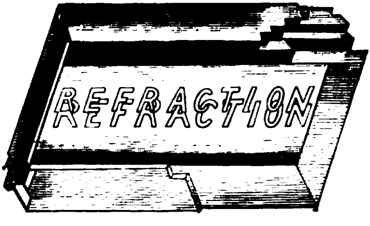

FIG. 22.—A crystal of Iceland spar, showing double refraction.

the blowpipe, it parts with its carbonic acid, and is reduced to lime. It can be easily scratched with a knife, and it dissolves with effervescence when placed in dilute acid.

Aragonite (IV., 3·7, 2·9) is chemically identical with calcite, but has a different crystalline form. It does not cleave so readily as calcite, and, when heated in the blowpipe flame, it rapidly falls into powder.

Chalybite, iron carbonate. It is often found mixed with clay, when it is known as *clay ironstone*.

Magnesite, magnesium carbonate.

Bitter spar, a double carbonate of calcium and magnesium, or, perhaps more correctly, a mixture of the two carbonates, as the proportions vary considerably (3·8, 2·9). In the massive form it constitutes *dolomite* rock.

Witherite, barium carbonate.

Strontianite, strontium carbonate.

Calamine, zinc carbonate.

Malachite, copper carbonate, combined with water. This is a beautiful green mineral, probably derived from the decomposition of copper ores. A blue variety is known as *azurite*.

(2) *Sulphates*.

Selenite (V., 2, 2·3), calcium sulphate, combined with water. This mineral is soft enough to be cut with a knife, readily cleaves, and is much addicted to twinning. The fine-grained, more massive form is called *gypsum*; and when very finely grained and mottled with impurities, it is called *alabaster*, and is used for decorative work. Gypsum is largely used for the manufacture of plaster of Paris, which is obtained as a white powder when the water is driven off from

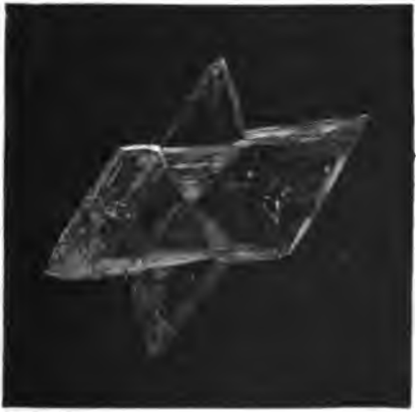

FIG 23.—Selenite, twinned crystals.

gypsum by heat. On mixing plaster of Paris into a paste with water it re-unites with it, and hardens, or "sets." Calcium sulphate, without water, forms a mineral called *anhydrite.*

Heavy spar (IV., 3, 4·5), barium sulphate. The weight of this mineral is at once noticed in hand specimens. It most frequently occurs in veins associated with mineral ores.

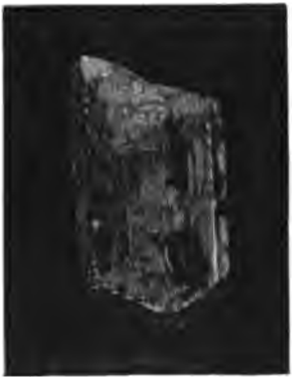
FIG. 24.—Heavy Spar.

(3) *Silicates.* These compounds constitute a very important group of minerals, as with quartz they make up nearly the whole mass of the igneous rocks. They are of much more complex and variable constitution than the other minerals, and there is often considerable difficulty in discriminating between them, and in making a satisfactory classification. It will be sufficient for our present purpose to arrange them under three heads, according to the character of their metallic or basic oxides.

(*a*) *Silicates of monoxides;* that is, compounds of metallic monoxides with silica.

Hornblende, or *amphibole* (V., 5·5, 3·2), a silicate of calcium, magnesium, and iron, but aluminium may be present and the other constituents are subject to variation. The colour of hornblende varies, but it is generally a dark green, and often almost black. It forms hornblende rock, and is an essential ingredient in syenite, diorite, and other rocks.

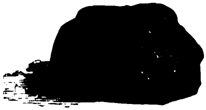
FIG. 25.—Hornblende.

Asbestos is fibrous hornblende, generally found filling cavities and clefts in limestones and serpentine rock. The name is derived from a Greek word meaning "unquenchable," from the fact that it will not burn. It is used in gas stoves, as packing in fire-proof safes, and occasionally for lamp wicks. It is sometimes found in a felted condition, when it is known as *mountain leather.*

Augite, or *pyroxene* (V., 5·5, 3·4). In composition and appearance this mineral much resembles hornblende; but, though belonging to the same crystalline system, its crystals may generally be distinguished from those of hornblende. It also cleaves differently, and has distinctive optical characters.

Jade (7, 3) is mainly a silicate of magnesium and calcium. It is hard and splintery, and has been used by prehistoric and uncivilized races for manufacturing into cutting implements, though in many cases it is not known where they obtained it.

Meerschaum (2, 0·9) is a hydrated silicate of magnesium, probably derived by secondary action from magnesite.

Talc, very similar in composition to the preceding. It is found both in the foliated and amorphous forms, the latter condition being known as *soapstone* or *steatite*. Steatite has a greasy feel, and in China is carved into a variety of forms, ornamental and otherwise.

Serpentine (4, 2·4), another hydrated magnesium silicate. Its green variegated colour, and faculty for taking a good polish, make it a valuable ornamental stone. It generally occurs as a rock.

(*b*) *Silicates of sesquioxides.* The chief sesquioxides are those of aluminium and iron, the former being much the most common. They are generally associated with monoxides as well.

Topaz (IV., 8, 3·5) is a silicate of aluminium combined with fluorine. It easily cleaves, and, when clear and of good colour, constitutes one of the precious stones. It is an essential ingredient in some rocks.

(*c*) *Silicates of both sesquioxides and monoxides.* The sesquioxide is almost invariably that of aluminium (Al_2O_3), while with it there may be present one, two, or more of the monoxides of potassium, sodium, calcium, magnesium. Iron sometimes occurs in this group, both as a monoxide (FeO) and as a sesquioxide (Fe_2O_3). The minerals of this group reach the highest degree both of complexity and variability, and by gradual shades and differences blend into each other in such a way that their recognition, without resorting to a chemical analysis, is almost impossible.

* *Felspar* (6, 2·4 to 2·8). All the felspars are silicates of aluminium united with some one or two monoxides. Next to quartz they are the most important rock-forming minerals, and they probably constitute nearly one half of the crust of the earth. They belong to two crystalline systems, V. (orthoclastic) and VI. (plagioclastic). The most marked varieties are, of system V., *Orthoclase*, or potassium felspar; and of system VI., *Albite*, or sodium felspar, and *Anorthite*, or calcium felspar. There are other felspars containing two monoxide bases, as, for example, *Labradorite* with calcium and sodium; but it is quite probable that they are only mixtures of the first named.

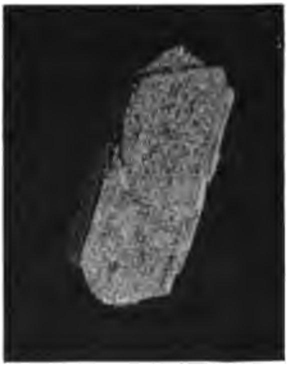
Fig. 26.—Orthoclase.

Though generally produced by igneous fusion, there are cases where felspars have evidently been deposited from an aqueous solution, as they sometimes appear in veins, and sometimes form "pseudomorphs"—that is, masses of one mineral having the crystalline form of another, a phenomenon very difficult to account for by igneous action, but quite commonly produced by the action of water. Felspar pseudomorphs of leucite are not uncommon. The sodium and potassium felspars are very subject to decomposition by the action of water containing carbonic acid. The acid unites with the alkaline bases and forms soluble carbonates, which are carried away in solution, leaving behind the silicate of aluminium in the condition of soft clay. A pure white felspar will thus yield a white clay known as *Kaolin*, largely used in the manufacture of china. Through this decomposition a hard granite rock is often reduced to a loose mass of gravel extending downwards for several yards, and only recognizable as granite by following it downwards to the unaltered rock, or by discovering in it nodules of undecomposed granite.

* *Mica* (2 to 3; 2·7 to 3). The micas form a group of silicates of very varied and variable composition. Their con-

spicuous character is their easy cleavage, in which they excel all other minerals. Mica is an essential mineral in many igneous rocks, especially in the granites. The most common variety is *muscovite*, which is a potash mica, and, under the incorrect name of "talc," is largely used for lamps, and in some cases for windows. *Biotite* is a magnesian mica. There are also micas in which lithium and lime predominate. But they all vary greatly, and the element which gives its name to the mica is often only one out of several.

Leucite (6, 2·5). A double silicate of aluminium and potassium resembling the felspars in composition. It is only found in volcanic rocks, where well-developed crystals may be often seen, although there seems to be some doubt as to which crystalline system it properly belongs.

Nepheline (6, 2·5) is somewhat similar to the preceding. It is found in lavas and in dolerite and basalt, sometimes entirely replacing the felspar in the two latter, and forming nepheline rock.

Garnet (I., 7, 3·5). This is another very variable mineral, or rather group of minerals, containing some or all of the monoxides of calcium, iron, manganese and magnesium, and the sesquioxides of aluminium, iron, and chromium. Like nepheline, it may form the main portion of a rock mass, which is then called *garnet rock*, or it may be an accessory as in some granite rocks and schists. It is very conspicuous in some of the schistose rocks of the Scotch Highlands, where it is the result of metamorphism. Garnets, when well developed and of fine colour, rank as precious stones under various names.

Epidote is a silicate of aluminium, calcium, and iron, occurring in cavities as columnar crystals, or in the fibrous and massive condition. It is generally of a greenish colour.

Beryl, a silicate of aluminium and beryllium. It is found as an accessory in schists. A bright green variety constitutes *emerald*.

Zeolites. These are hydrated silicates. The name is derived from a Greek word, meaning *to boil*, and has been given to them because they froth up when fused, owing to the escape of steam. They contain from four to twenty-two per cent. of water. They chiefly occur in fissures and cavities of volcanic rocks, or they may be essential ingredients of basaltic and other rocks. In either case they are the result of subsequent metamorphic action. There are very many kinds, differing much in composition and in crystalline form. Among them may be named *prehnite* with calcium as a predominating monoxide base, and *natrolite* and *analcite* with sodium.

Chlorite, a hydrated double silicate, often of a greenish colour. It is an important ingredient in chlorite schists and in diabase, etc.

Glauconite, somewhat similar to chlorite, often occurring as internal casts of foraminifera and other minute fossils. It is very characteristic of some formations of the cretaceous system, to which it gives the colour which has obtained for them the name of "greensand."

Tourmaline (*schorl;* III., 7, 3). This is a silicate of very complicated composition, some eight or nine metallic bases being named as taking part in it, together with boron, which appears to be always present. It is an essential ingredient in schorl rock, and often an accessory in mica schist and granite. It is not found in volcanic rocks. It is often found in hexagonal prisms which have the peculiar property, when heated or cooled, of becoming charged with positive electricity at one end, and negative at the other. Certain varieties polarize light when it is passed through them.

Hauynite is a silicate and sulphate of aluminium, calcium, and sodium. It is often found of a rich blue colour, when it is called *lapis lazuli.* This stone, when powdered, supplied the valuable pigment known as ultramarine, but for this purpose it is quite superseded by the artificial product.

(4) Other salts.

Borax is borate of sodium united with water. It is very soluble, and most of it is obtained from the borax lakes of the United States, or prepared from the boracic acid of the Tuscan lagoons.

Nitre is nitrate of potassium or sodium, another soluble mineral generally found as an efflorescence on or near the surface in certain nearly rainless districts, notably the desert of Atacama, in the north of Chili.

Apatite is mainly a phosphate of calcium with fluorine and chlorine present. It occurs as an independent rock, as concretions, as an accessory in some igneous rocks, and in veins associated with tin ores. It is largely used as a manure.

7. **Organic Mineral Matters.**

Coal mainly consists of carbon, with varying quantities of hydrogen and oxygen, together with mineral impurities. It is the result of the metamorphism of vegetable matter, and occurs in strata of varying thickness among other rocks. Further details will be given later on.

Amber is a fossil gum derived from trees resembling our fir-trees. Its origin is plainly shown by the presence of a great variety of embedded insects. It is largely found in the deposits along the Baltic shores of Prussia.

The following table gives the percentage of the chief minerals in the earth down to a depth of sixty miles, on the assumption that the first three miles consist of aqueous rocks, and the remaining fifty-seven of igneous.

Felspar	48
Quartz	35
Mica	8
Talc	5
Carbonates of lime and magnesia	1
The rest	3
	100

CLASSIFICATION OF MINERALS.

I. *Elements.* Native copper, silver, and gold; carbon as diamond and graphite; sulphur.

II. *Sulphides.* Blende, galena, copper glance, cinnabar, pyrites, realgar, orpiment, stibnite, mispickel, copper pyrites.

III. *Chlorides.* Rock-salt, sal-ammoniac.

IV. *Fluoride.* Fluor.

V. *Oxides.* Cuprite, spinel, magnetite, hæmatite, corundum, pyrolusite, cassiterite, quartz.

VI. *Oxygen-salts.*

(1) *Carbonates:* calcite, aragonite, chalybite, magnesite, bitter spar, witherite, strontianite, calamine, malachite.

(2) *Sulphates:* selenite, heavy spar.

(3) *Silicates:* (*a*) hornblende, augite, jade, meerschaum, talc, serpentine.
(*b*) topaz.
(*c*) felspars (orthoclase, albite, anorthite, labradorite), mica, leucite, nepheline, garnet, epidote, beryl, zeolites, chlorite, glauconite, tourmaline, hauynite.
(4) Other salts; borax, nitre, apatite.

VII. *Organic mineral matters.* Coal, amber.

QUESTIONS.

1. Mention, in order, the six most common elements, with the names of some minerals which contain them.
2. Describe the chemical principles upon which the preceding classification of minerals is based. Could they be classified in any other way?
3. Describe the chemical and physical characters of quartz, pyrites, mica, fluor, hæmatite, augite, leucite, calcite, heavy spar, talc, selenite, felspar.
4. Classify the minerals named in question 3; select five which are most common in the earth's crust, and arrange them in order of the relative abundance, explaining what is here meant by the term *crust*, and what assumption is made respecting it.
5. Why are the silicates so important? How may they be classified?

CHAPTER IV.

ROCKS (1).

THE term *rock* is applied in geology to any of the materials, hard or soft, whether consisting of one mineral or of several, which go to form the solid earth. The technical use of the term, therefore, has a wider signification than the popular one, inasmuch as technically it includes such materials as clay, loose sands, and gravels, which are not popularly spoken of as rocks.

All rocks are made up of one or more minerals. Those which contain more than one mineral are merely mechanical mixtures of them, not chemical compounds; and they differ much as to the coarseness or fineness of the mixture. In some, such as granite, the constituent minerals can be detected easily with the naked eye; while others, such as the finer basalts, look quite homogeneous. As the constituent minerals may be found mingled in almost any proportion, so also other minerals, over and above the essential constituents of the rock, may also be present in smaller quantities, and give the rock a special character. The determination of the constituent minerals of a rock is often a very difficult matter, especially when it is very compact and fine grained. A chemical analysis of the rock as a whole throws very little light upon it, inasmuch as the elements detected may be derived from a great variety of different minerals; and it is generally quite impossible to separate the various minerals from each other, either mechanically or chemically, in a satisfactory manner. At the same time, much useful and suggestive information may be got from a chemical analysis; as, for example, the percentage of silica present will enable us to decide whether the rock belongs to the "acidic" or "basic" class, and will thus enable us to exclude many rocks from the consideration.

The application of the microscope to the discrimination of rocks by **Sorby** and **Zirkel** has been a great aid to the study. The method consists in cutting and polishing a very thin slice of the rock, placing it on the stage of the microscope, and examining it, either by the aid of ordinary or of polarized light. By this means a great deal has been learnt about the composition of rocks. The presence of minerals has been detected in rocks where they were previously unknown; compact and even vitreous rocks have been seen to be partly crystalline; and, on the other hand, rocks which were thought to be wholly crystalline, have been seen to be partly composed of amorphous mineral matter. In addition to this, various minute cavities and bubbles, often full, or partly full, of water or liquid carbonic acid, have been detected in many crystals, and have thrown light upon the conditions under which they were formed.

Rocks differ from each other very much in texture. After the inspection of a complete series of rocks, perhaps the most obvious distinction would be the crystalline and non-crystalline character, though a more minute examination would result in the removal of some from the latter to the former division. The crystalline rocks vary much as to the size of their crystals, and this is, no doubt, due to the varying conditions under which the crystallization has taken place, those with the largest crystals having, it is believed, cooled more slowly than the others, and having thus allowed the molecules of the crystallizing material a longer period in which to arrange themselves. From this it is evident that two rocks may be exactly similar in mineral composition, but one may be coarsely crystalline, and the other fine-grained, because they have solidified under different conditions. The glassy, or "vitreous," condition is due to the very rapid cooling of a rock rich in silica. Sometimes one constituent may be much more crystallizable than the remainder of the rock; and in this case it might result that the main mass of the rock would be compact and fine-grained, while there would be large crystals of the other mineral embedded in it. Such a rock is called a *porphyry*. If the matrix is granular, with conspicuously large crystals in it, the rock is said to be *porphyritic*. The granites of Shap and Dartmoor are called porphyritic granites because they contain large crystals of red and white felspar respectively. Sometimes cavities, such as bubbles in lava, become subsequently filled up with mineral matter; such a rock is not porphyritic, but *amygdaloidal*. If the bubbles are not filled up, the rock is said to be *vesicular*; and if they are so numerous as to give the rock a cindery appearance, it is said to be *scoriaceous*; or if this is carried to a great extent, and the rock consequently rendered very light, it is called *pumiceous*.

Some rocks, for one reason or another, can be readily split into thin layers; and there are several terms in use to express this property. If the rock splits into thin leafy sheets, which are all pretty much alike, and which lie parallel to the stratification of the rock, it is said to be *laminated*, and the thin layers are called *laminæ*. It is really a fine kind of stratification. It is often seen in fine-grained sandstones, where it is generally caused by the presence, at frequent intervals, of fine layers of mica particles. Such sandstones are called *flagstones*, and, according to their thickness, the layers are used for roofing or for pavements. Shale, a fine-grained clayey rock, is generally very finely laminated. Ordinary roofing slate is another case of a rock splitting readily into thin sheets; but here the sheets are as a rule by no means coincident with the lines of stratification. This structure is called *cleavage*, or, to show that it has no connection with the cleavage manifested by crystals, *slaty cleavage*. From observation in the field, strengthened by experiments, this particular structure is believed to be due to enormous pressure at right angles to the lines of cleavage. Another case is that of the schists, such as mica schist, chlorite schist, etc. A careful examination of these rocks will show that their different layers are really layers of different mineral matter; a thin layer of mica, for instance, will be found lying between two thin layers of quartz. In gneiss, also, the same structure may be seen. The gneiss is often of exactly the same composition as a granite; but the mineral matter, instead of being a mass of crystals mixed in an indiscriminate manner, is arranged in layers, as above described. These layers are often very much twisted and crumpled, and present quite a different appearance from the cases previously described. This texture is called *foliation*, and the rocks are said to be *schistose*. It seems to be the result of chemical changes produced under great pressure when the rock is very hot and saturated with water.

Most of the foregoing characters of rocks could be noted in hand specimens, but, in order to get a true idea of rocks, they should be examined out-of-doors, "in the field." In regarding them thus on the large scale, it would be noticed that many of the rocks repose in great horizontal layers, or *strata*, one on the top of the other. In some cases these layers are more or less tilted, bent, broken, or dislocated, but their stratification is rarely disguised. Such are the beds of chalk, limestone, sandstone, and clay, which may be seen in many parts of England and other countries. Other cases, however, would be noticed of rocks rising up in huge masses, cracked and split vertically and horizontally, but presenting no signs of bedding. The granites are rocks of this kind. The stratified rocks contain fossils, and, if made up of small particles, these particles are mostly smooth and rounded, and the rocks show every sign of having been originally deposited by water, and for this reason are also called *aqueous*. The unstratified rocks are generally more or less crystalline, do not contain fossils, and seem to have once been in the molten condition. They are therefore called *igneous.* The schistose rocks are somewhat intermediate in character. They are often plainly stratified, and yet they have no other character in common with the ordinary stratified rocks. They are believed to have undergone a good deal of change since their original deposition, and are known as *metamorphic* rocks. We thus get our three great divisions of rocks, the aqueous, igneous, and metamorphic.

I. AQUEOUS ROCKS.

The rocks of this class are composed of small particles which are derived from the wearing away of other rocks, of matter deposited from solution in water, or from organic material.

1. The sedimentary materials are such as would be washed off the surface of the land by the rain and rivers or detached from the cliffs by the sea. We see the process of rock destruction and reconstruction going on at the present day. The rivers are bearing mud and sand to their mouths, and spreading it out in shallow water in great horizontal layers, in which are buried all sorts of marine remains, together with many things brought down from the land by the rivers. The waves beating on the cliffs are breaking up the rocks and grinding them to powder, and spreading out the broken material in great stretches of sand. On coral reefs and shell banks great masses of calcareous material are being piled up to form future beds of limestone. There is, therefore, no difficulty in understanding how these great horizontal beds of clay, sand, and limestone have been formed.

(1) Rocks formed of clay or mud; **argillaceous** rocks.

Pure clay is silicate of aluminium, and is no doubt derived in the first instance from the decomposition of the felspar in the igneous rocks. But, like most other materials, the clay of any particular stratum may have gone through a variety of changes since it was formed. It may have been washed off the surface of some ancient decomposed granite, carried down to the sea or spread out in a lake, and then hardened into shale. After a long period this shale may have been again converted into mud, perhaps by the passage over it of some

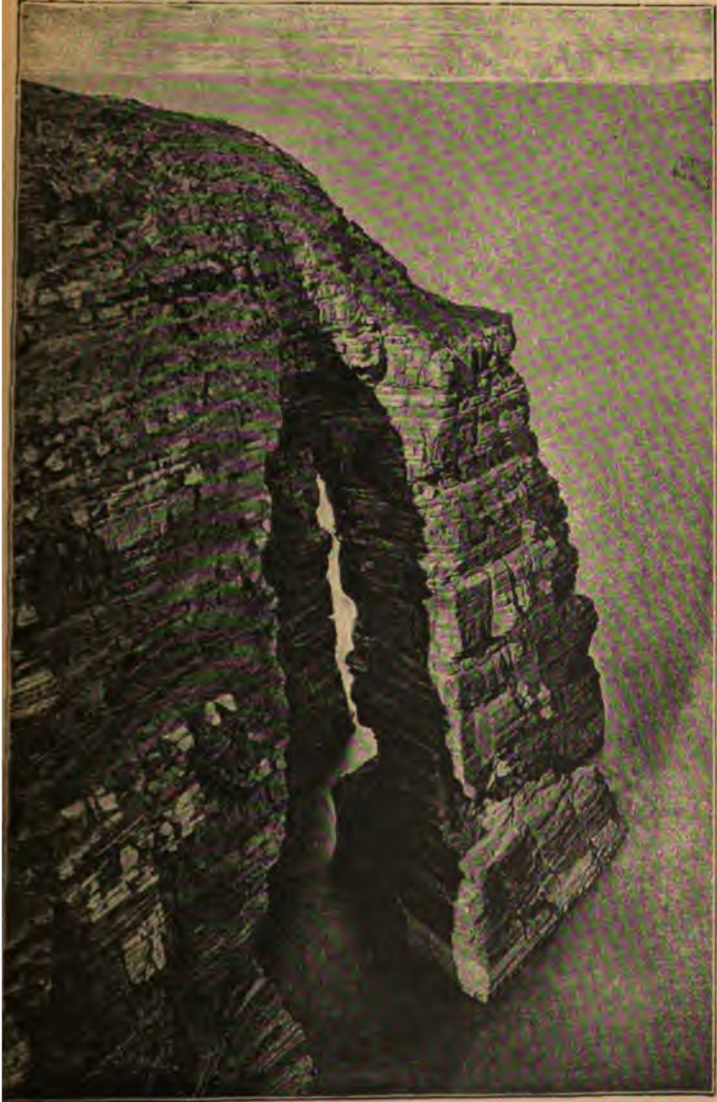

FIG. 27.—The Gloop, Duncansby Head; Old Red Sandstone. (Wilson.)

great ice sheet, and once again spread out, perhaps mixed with other material from another source, and so again have taken its place among the stratified rocks. It is, therefore, no matter for surprise to find that most clays are not pure aluminium silicate, but mixtures of various other fine ingredients. The dark colour is generally caused by the presence of carbonaceous or bituminous matter derived from animal or vegetable organisms; and the red or brown colour of many clays is due to oxides of iron, which are present in large or small quantities in most rocks. When mixed with sand in sufficient quantity it is called *loam* or *brick earth.* In this condition it forms an excellent agricultural soil, and is largely used for brick-making. A large proportion of sand forms *fire-clay*, used for making fire-bricks for stoves and furnaces. Calcareous matter converts the clay into a *marl*, which, when hardened, is called *marlstone. Fuller's earth* is a hydrated silicate with excess of silica, which falls into a powder when put into water, and which is used for "fulling," or removing the greasy matter from cloth. The various clays, pure and impure, when hardened and laminated constitute *shales*, of various characters; such as bituminous shales, micaceous shales, etc. Industrially they are of great value in brick, tile, and pottery making.

(2) Rocks formed of sand; **arenaceous** rocks.

The preceding group of rocks results from the decomposition of mineral matter and its reduction to an impalpable material. When the mineral matter is merely comminuted and converted into small more or less worn and rounded grains, *sand* is produced. Quartz, being very abundant, and at the same time very hard and undecomposable, is the chief source of this material; but in exceptional cases sand may be composed of almost any kind of rock, and in nearly all cases it contains an admixture of particles of mica, pieces of felspar, grains of glauconite, etc. When the sandy particles are cemented together various kinds of sandstone are produced, differing from each other and receiving special names according to the character of the sandy grains and the nature of the cementing material. Thus we have *micaceous, felspathic* and *green sandstones*, containing, as well as quartz, fragments of mica, felspar, or glauconite. The smaller the quartz grains the finer the grain of the sandstone; those with larger and less water-worn grains are called *grits.* Looking at the nature of the cement, we have *argillaceous*, *calcareous*, *siliceous*, *ferruginous*, and other sandstones, where the grains are held together by clay, carbonate of lime, silica, iron oxides, etc. All sandstones are stratified: those which are very finely stratified constitute the laminated, or *flaggy*, *sandstones* before described, while the thicker beds, suitable for building purposes, are called *freestones.* Certain dark fine-grained argillaceous sandstones found in the older stratified rocks are often called *greywacke.* Many other terms are applied by quarrymen and miners to local sandstones; and topographical names are frequently used in geology to denote strata which are well known or are specially developed in different places. Of the latter kind are *Thanet sand*, *Harlech grit*, *Bagshot sand*, etc.

The two foregoing classes constitute what are called sedimentary rocks, that is, rocks formed of sediment deposited in water. This sediment, it will be observed, is, in the first instance, derived from the decomposition of the igneous rocks; and the two kinds of rock are respectively derived from the two minerals which far exceed in quantity and importance all the rest, viz. felspar and quartz, the clay rocks being the result of chemical decomposition, the sandstones of mechanical disintegration.

Conglomerates are rocks formed of pebbles or shingle cemented together, and are of very various composition. They are geologically interesting, inasmuch as the pebbles which are embedded in a conglomerate must have been derived from a rock of much greater antiquity than the conglomerate itself. For example, if we find a conglomerate resting on slate, and containing slate pebbles, we know that the slate must have been in existence before the conglomerate was laid down, and consequently that an enormous period

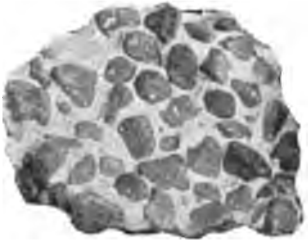

FIG. 28 —Conglomerates.

must have elapsed between the time when the mud of which the slate was formed was deposited by water and the time when the conglomerate was accumulated.

A *breccia* is a rock composed of angular and rough fragments cemented together. In many caves *bone breccias* occur, formed of bones of animals cemented together by stalagmite.

Tufa is a compound of volcanic fragments hardened together into rock, but, as it is primarily due to igneous, rather than aqueous, action, it will be more conveniently considered in another place.

2. Another important group of aqueous rocks is those which are formed of the material which has been dissolved in water, and has been deposited therefrom by chemical action. By far the largest class of rocks belonging to this division comprises those consisting of carbonate of lime deposited by "hard water" when it emerges into the air. Water can only keep carbonate of lime dissolved as long as it contains carbonic acid gas dissolved in it as well. This gas it obtains from the air and soil, and thus is able, when it penetrates into the rocks, to dissolve some of the limestone it meets with. On emerging again into the air from some spring, some of its carbonic acid escapes into the air, and the water is then no longer able to retain the limestone in solution, and so deposits it on anything over which it flows. Such springs are called *petrifying springs*, because they encrust with stone anything put into them. In precisely the same way a stony deposit is formed in kettles and boilers where hard water is used. Carbonate of lime, or limestone, so formed is called *travertine*, *tuff*, or *calcareous tuff*, or sometimes *tufa*, though it is better to restrict the latter term to volcanic formations. A notable deposit of travertine is that which exists near Rome, formed by a tributary of the Tiber, and from which building material has been quarried for many centuries. The stalactites on cavern roofs are of the same nature. They have been left by the dripping water, forming long sticks like icicles, or thin translucent sheets which ring like a bell when struck. The more massive material on the floor, which often cements together the fallen *débris* from the roof and sides and other matter brought into the cave by various agencies, is called

stalagmite. There are some curious limestones formed of little round particles of calcareous matter, which, when carefully examined, are found to have a structure something like an onion, being formed of a tiny grain of some foreign substance in the centre, covered with concentric layers of carbonate of lime. These are not very easy to account for, but it is probable that the calcareous matter has been deposited from water, somewhat like stalagmite and the other deposits just described, or they may be of organic origin. If the grains are comparatively small, the stone is called *oolite* ("eggstone"), if larger, *pisolite* ("peastone").

Some of the *dolomites*, which are rocks consisting of an admixture of carbonate of lime and carbonate of magnesia, are also chemically formed, though probably, in some cases, much of the chemical action has taken place subsequently to the original deposition.

Gypsum, which is sulphate of lime, is another rock of this class. Sometimes it is found in thin beds, having a fibrous texture something like cocoanut, in which form we should consider it as a mineral rather than a rock; as are also the transparent crystals (*selenite*) found in many clays. Sometimes, however, it is more massive and compact. *Alabaster* is a compact non-crystalline form. Beds of gypsum are often associated with beds of *rock-salt*, another chemical deposit.

Heated water has the power of dissolving quartz or silica in small quantity, and of course, on cooling, deposits it again. Hence large deposits of siliceous matter, sometimes tinted with various foreign matters, are found round hot springs. This deposit is called *siliceous sinter.*

In connection with the subject of chemical deposition, we may consider a process, common in stratified rocks, which results in the formation of *nodules* and *concretions.*

Every one who has seen chalk cliffs is familiar with the layers of more or less flat irregular masses of *flint* which are found in the upper portion of the chalk strata, or with the isolated and scattered flints of the middle portion. A closer examination soon leads to the conviction that these flints were not thrown down with the chalk, but have been formed since.

For instance, a convincing proof that some of the flint, at any rate, is much more recent than the chalk, is the fact that vertical and oblique cracks and joints in the chalk strata are often filled in with it. Moreover, many of the flints, especially the scattered ones, seem closely connected with the chalk fossils, especially with the fossil sponges, which are very often completely turned into flint, and not unfrequently are wholly or partly embedded in it. There is therefore little doubt but that the flints are due to some chemical process, by which the silica scattered through the chalk has been dissolved by percolating water, and then deposited as we now find it.

Chert is very similar to flint, but contains a certain amount of calcareous matter, and is more opaque. It is found in the harder limestones, much as flint is found in chalk; but, as the contrast in colour is much less, it is not so noticeable.

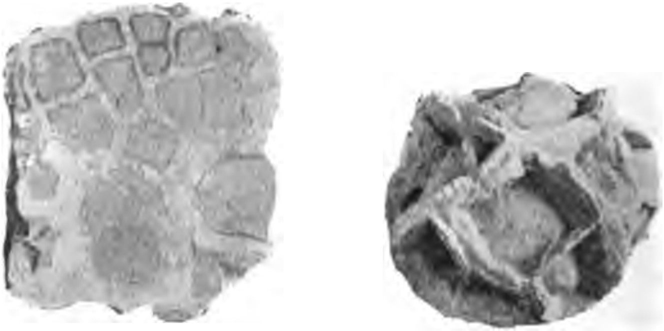

FIG. 29.—Septaria from the London clay. Section and exterior. (Jermyn Street Museum.) The nodules consist of clay, with wide cracks filled with calcite.

By a somewhat similar process, large nodules of carbonate of lime, called *septaria*, are formed in beds of clay. They contain more or less clay, and are ground up for cement. A valuable ore of iron, the *clay ironstone*, occurs in nodules in beds of clay. It has been alluded to in the chapter on minerals.

In a clay called the gault, and in some sandy beds which lie below it, nodules known as *coprolites*, composed of a mixture of phosphate and carbonate of lime, are found. They are of organic origin, and are largely ground up for manure, for the sake of their phosphorus.

Nodules of *iron pyrites* are also common in the gault, and also in the lower chalk. They are often nearly spherical, and have a fibrous radiating structure.

All these concretions are formed by the gradual separation of their material from the rock in which they are formed, and its re-disposition in its present form. It is somewhat puzzling to say why they have been formed where and as they now are; but in most cases they seem to have gradually accumulated round some small mineral particle or some fossil which served as a nucleus. Flinty sponges in the chalk appear to have acted very generally in this manner, being now often quite enveloped in a mass of flint the external form of which conforms to the shape of the sponge.

Other valuable iron ores are also due to chemical action, though they do not, as a rule, occur as nodules. Such is *hæmatite*, the sesquioxide of iron with or without combined water. It occurs in thick beds in Furness and in Cleveland. *Magnetite* also forms thick beds; and both these iron ores occur in beds so massive that they may be fairly regarded as rocks.

3. The third division of aqueous rocks consists mainly of limestones derived from the shells or other hard parts of marine organisms, and of carbonaceous beds formed of plants. The hard parts of most animals, whether on land or water, consist of some compound of lime. Most limestones are formed of the remains of animals which have lived in the water, such as corals or shell-fish of various kinds. Often one particular form prevails so largely that it gives its name to the limestone. Thus we have *coral limestones*, both ancient and modern. Some limestones are made of portions of a peculiar kind of fossils called encrinites, and are hence called *encrinital limestones*. In Egypt and elsewhere there are large beds of limestone entirely formed of the flat shells of nummulites, a species of foraminifer. This is called *nummulitic limestone*. *Chalk*, which is a soft white limestone, is largely composed of the shells, whole or broken, of foraminifera. Certain limestones are called *hydraulic limestones*, because they are used for

making hydraulic cement—that is, cement which will harden under water. These limestones contain clay and silica. The best-known stones of this kind are the septaria, which we have placed in the preceding group, and certain Liassic limestones.

But there are in the sea, especially in the tropics, minute creatures with beautiful shells formed of silica. These are chiefly polycystina and diatoms; and there are also flint sponges. When their remains are deposited without much admixture of other matters, a siliceous rock is the result; but such rocks formed in this way are rare, because the siliceous shells, when they sink to the bottom of the sea, instead of making a deposit by themselves, become mingled with the more numerous calcareous shells. The flint and chert already described are no doubt derived in a secondary way from these organisms.

The rocks derived from plants, in a greater degree than the plants themselves, consist largely of carbon, and have been formed by a gradual chemical change which has taken place in the vegetable matter while it has been embedded in the rocks. The nature of this vegetable matter, how it got embedded, and the nature of the change it has undergone, will be explained later on. According as it has been altered, little or much, it is more or less like its original condition. *Peat* and *lignite* still retain visible traces of their origin; *coal*, as a rule, does not. *Anthracite*, *bitumen*, *plumbago*, and *jet* are still more altered forms.

SUMMARY.—1. Rocks form the crust of the earth, and may consist of one mineral or a mixture, coarse or fine, of two or more.

2. The two chief ways of investigating their composition are chemical analysis and microscopical examination, sometimes aided by polarized light. The latter method also reveals cavities and bubbles before unobserved.

3. The texture of igneous rocks depends on (*a*) rate of cooling, (*b*) the minerals present. They are sometimes vitreous, porphyritic, amygdaloidal, vesicular, pumiceous.

4. Stratified rocks may be laminated, cleaved, foliated.

5. All the rocks of the earth's crust are grouped into three divisions: (1) aqueous, (2) igneous, (3) metamorphic.

6. **Classification of aqueous rocks.**
   - (1) *Sedimentary.*
     - (*a*) *Argillaceous:* clay, loam, fire-clay, marl, marl-stone, fuller's earth, shale.
     - (*b*) *Arenaceous* and *fragmentary:* sands of various kinds, sandstones, grit, conglomerate, breccia.
   - (2) *Chemically deposited:* calcareous tuff, stalactite, stalagmite, oolite, pisolite, dolomite, gypsum, rock-salt, sinter, nodules—such as septaria, ironstones, iron pyrites, etc.
   - (3) *Organic rocks:* various kinds of limestone, coal, peat, lignite, anthracite, bitumen, plumbago, jet.

QUESTIONS.

1. What difficulties are encountered in trying to ascertain the mineral composition of rocks? How are they to some extent surmounted?
2. Describe what can be learnt by the application of the microscope to petrology.
3. How do you account for the variety of texture in crystalline rocks?
4. Distinguish between *lamination*, *cleavage*, and *foliation*. What rocks possess these characters, and how are they caused?
5. Upon what principle are rocks classified? Name the great classes, and briefly describe their characters.
6. What is the difference as regards origin of shale, gypsum, and jet?
7. Describe the various (*a*) sandstones, (*b*) limestones often met with.

CHAPTER V.

ROCKS (2).

II. IGNEOUS ROCKS.

THE igneous rocks, which form the second great division, are very much more complex in structure and in composition than the aqueous rocks. They contain a greater number and variety of minerals; and the minerals themselves, being nearly all double silicates, are of greater complexity. The mineral components may be in a coarsely crystalline condition, and easily distinguishable, as in granite; they may be so intimately mixed as to be frequently undistinguishable from each other, as in some basalts; they may be fused into a glassy mass, as in obsidian or pitchstone; loose and open in texture, like pumice; or more or less sedimentary or stratified, like volcanic ash. These varieties of texture, though depending to some small extent on the mineral constituents, yet are mainly caused by the different conditions under which the rock has cooled and solidified; the slow cooling of a large mass tending to produce fully developed crystallization, quick cooling the glassy and compact states. It may happen, therefore, that two rocks may be practically alike as regards mineral composition, while one may be crystalline and the other not. A large mass of molten material might, for example, exist underground at a great depth, and a portion of it might be forced upwards and ejected from a volcanic crater. This latter portion, in cooling, would become scoriaceous and cindery on the top, and close-grained and compact in its centre; while the portion below, cooling and solidifying more slowly, would be perfectly crystalline; and yet, as far as chemical composition is concerned, they would be all alike. It should be noted, also, that these igneous rocks, even more than the aqueous, are not separated sharply from each other, but that one kind blends by insensible gradations into another. The number of varieties of granite, both as regards composition and texture, is very great. The kind of felspar which prevails differs in different specimens, and the relative quantities of the constituent minerals is rarely alike in two specimens. As regards texture, we have, on the one hand, the coarsely crystalline porphyritic granites of Dartmoor and Shap, with embedded felspar crystals several inches long, and, on the other hand, many of the granites of Germany are extremely fine-grained, as are some at Loch Etive in Scotland, and Liskeard in Cornwall; while the greater number have an intermediate position. Basalt, again, a close-grained compact rock, gets coarser and more visibly crystalline till it becomes dolerite; but it is impossible to say where basalt leaves off and dolerite begins.

It is much easier to explain why igneous rocks differ in texture than why they differ in composition. They are all derived, as we believe, from the original molten matter of the once fluid earth. Some have been thrust upwards and have solidified at or near the surface, while others have solidified at a more or less considerable depth. These different conditions of cooling will explain differences of texture. But why should these igneous rocks differ in composition if they are all derived from the same molten mass? Why should one rock be rich in orthoclase felspar, and another in labradorite? Why should one have hornblende while another has augite? All the various minerals of igneous rocks are built up for the most part by ringing the changes on a comparatively small number of elementary compounds, such as silica, alumina, oxide of iron, lime, magnesia, soda, potash, and water. From a selection of these practically all the essential minerals of the igneous rocks could be constructed; and it is thought possible that the varying pressure, temperature, and other conditions may influence or favour the production of one or other mineral. But in all these matters we are very much in the dark. Other difficulties have been raised, as, for instance, why in ordinary granite crystals of felspar should exist in a matrix of quartz, rather than crystals of quartz in a matrix of felspar,—quartz being the least fusible of the two, and therefore likely to solidify first. But we know, from chemical experiments, that when substances are mixed they do not act exactly as if they were alone. When an alloy of lead and silver, for example, is melted up and then cooled, masses of pure lead first crystallize out and leave all the silver still liquid, although silver naturally solidifies at a much higher temperature than lead. Again, it occasionally happens that substances are found in granite which we can hardly believe have been formed by solidification from fusion; such as pyrites and carbonates of lime and magnesia. These, no doubt, have been formed subsequently by chemical changes in the rock itself; and their occurrence in recent lavas shows conclusively that they are no proof that any rock in which they occur is not igneous.

Silica, either free or combined, is by far the most abundant constituent of the igneous rocks. It is rarely less than 45 per cent. of the rock, and sometimes rises as high as 80 per cent. This varying percentage of silica is often made use of in the classification of igneous rocks; those having above 60 per cent. being called *acidic*, and those having less, *basic*. The latter, having a larger proportion of the metallic oxides, are heavier than the others; and it has been suggested that, when the earth was completely fluid, the lighter silica would tend to rise to the surface and solidify first, so that the most ancient igneous rocks should be of the acidic class, and the more recent ones, derived from a lower stratum of the molten material, should be basic. There is some truth in this; but the exceptions are so numerous that the theory cannot be considered of much value.

In classifying the igneous rocks, it will be most convenient to place the more or less coarsely crystalline rocks, which have cooled slowly far beneath the surface, into one class, called *Plutonic*, and those more or less compact, vitreous, or scoriaceous rocks, which have been cooled at or near the surface, into another, called the *Volcanic*. They can further be subdivided when necessary into *acidic* and *basic*.

1. *Volcanic rocks*. There have apparently been volcanic outbursts at all geological periods, but as many of the more ancient volcanic rocks have been either denuded away or covered up, it follows that most of the known volcanic rocks are somewhat recent. A volcano is a hole or fissure in the earth's crust from which various materials, gaseous, liquid, and solid, are at times expelled and scattered round the opening or crater. One very abundant gaseous material is steam, which is blown upwards with great force high above the volcano, condenses, forming a great cloud, and falls as rain, bringing with it a large portion of the dense cloud of dust, which, thus converted into mud, forms an accumulation on the leeward side of the volcano. With it are also mingled coarser materials, formed, like the dust, by the knocking together of rocky material torn from the sides of the cavity. This broken material is called "ash," and when more or less solidified is called *tufa*, or *volcanic tufa*. It is spread out in a more or less stratified manner; at one time on one side of the volcano, and at another time on another side, according to the direction of the wind, and is generally the most abundant product of volcanic action. Wide-spreading and thick beds of it extend over the Neapolitan area, where it consists of a fine yellowish grey clayey material, largely used in cement-making. There and in other districts it has evidently fallen into the sea, and in many cases it contains marine sediment and even marine

fossils, and might therefore quite legitimately be considered an aqueous rock. Volcanic ash is not at all uncommonly met with interstratified with some of our most ancient aqueous rocks.

Another product of volcanoes is the *lava.* This is molten or half-molten rocky material, containing a large quantity of water, which escapes from it in the state of steam, filling the upper portion of the lava stream with bubbles, and rendering it light and cindery. As it cools it becomes compact in the central and lower portion, and sometimes presents a peculiar columnar appearance, partly perhaps due to the development of cracks on cooling, and partly to a kind of rough attempt at crystallization. This structure may be seen in remarkable perfection in the Island of Staffa (Figs. 33, 34), and in other places on the west coast of Scotland, and at the Giant's Causeway in the

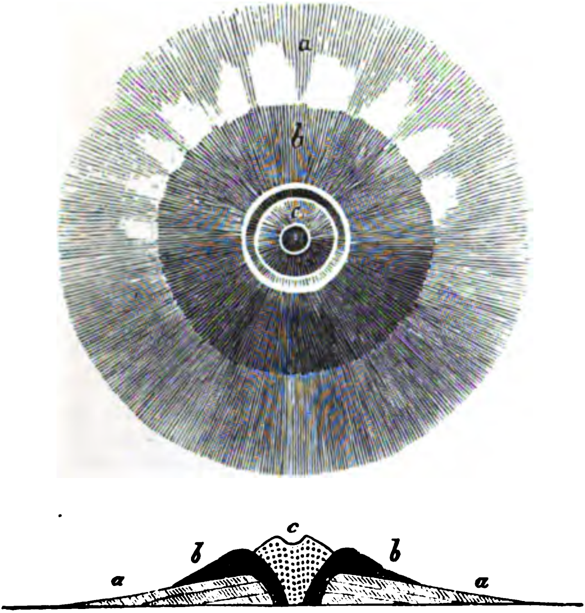

FIG. 30.—Plan and section of a composite volcanic cone.
a, tuff; *b*, lava; *c*, ashes and scoriæ.

north of Ireland. The rocks at these localities seem to be vestiges of an enormous outpouring of lava, which, judging from its thickness and the large extent of country over which it spreads, must have been of an unusually fluid character.

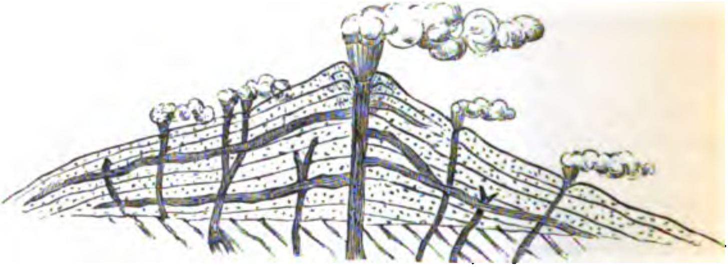

FIG. 31.—Ideal section of volcano showing dykes of lava and lateral craters forming lateral cones.

Sometimes the lava, instead of being forced out at the crater, is forced into, through, and among the surrounding rocks, either filling joints and cracks in them, forming *dykes*, or in some cases forcing itself in between two other strata, and producing the appearance of having been interbedded. Lavas differ considerably in character, and bear different names according to their texture and mineral composition. The dense columnar lava of Staffa is *basalt*, and is a fine mixture of labrodorite (lime felspar) and augite. If coarser in texture it is called *dolerite;* and probably *gabbro*, a still more granular rock, may be regarded as its plutonic equivalent. They consist of felspar and augite, with more or less iron oxide, and all belong to the basic division. In colour they are dark-green or black. The term *trap* is applied to some dark basaltic lavas of variable composition, which spread out in great sheets over a large extent of country, as in Sweden and the Deccan.

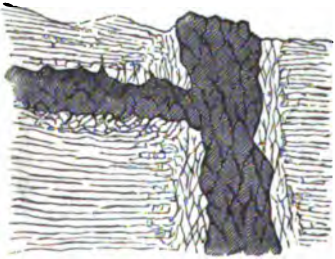

FIG. 32.—Dyke and intrusive sheet of dolerite.

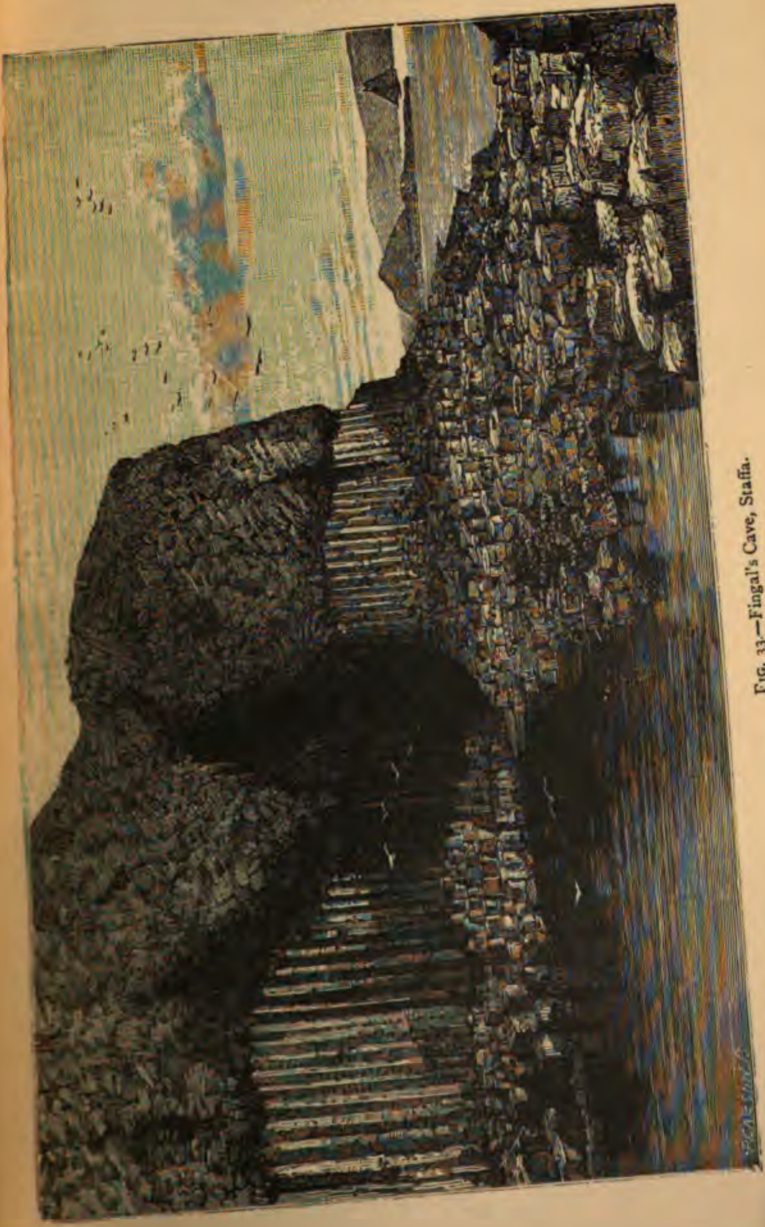

FIG. 33.—Fingal's Cave, Staffa.

They do not necessarily differ in composition from ordinary basalts, but are more widespread, either on account of greater original fluidity, or perhaps because they were extruded from a long fissure instead of from a crater.

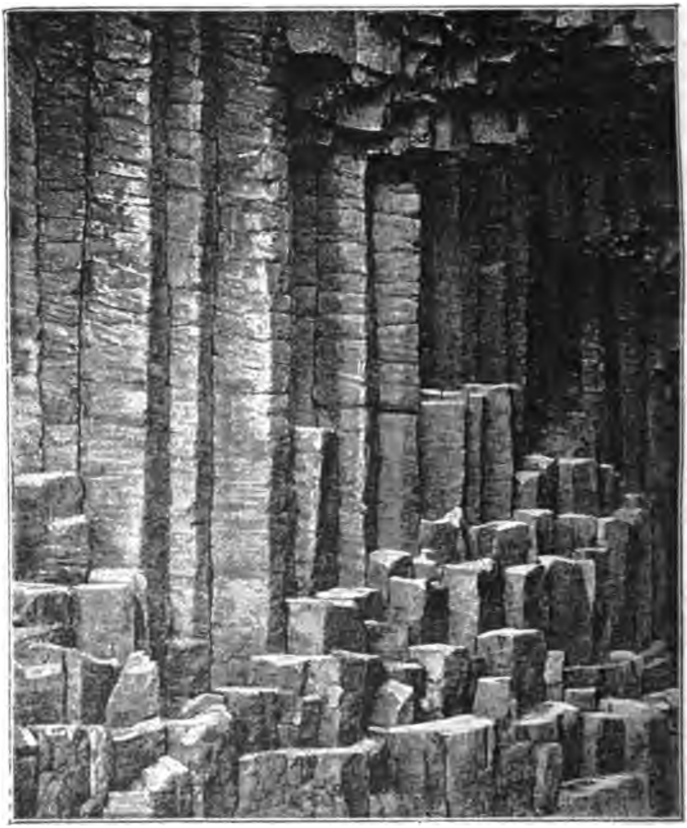

FIG. 34.—The Basaltic columns at Fingal's Cave. An enlargement of the left side of entrance. (Wilson)

There is another group of volcanic rocks which are acidic in character, being richer in silica, poorer in lime and iron oxides, and as a rule lighter in colour. The chief of these are the *trachytes*, which derive their name from their rough feel when handled. They vary very much in composition, and petrologists are not all agreed as to what rocks are to be included under the term; but they generally contain two varieties of felspar, neither of them being labradorite, and hornblende, with augite present in small quantity if at all. They are often porphyritic. *Obsidian* is a glassy form of trachyte, also sometimes porphyritic and vesicular; when excessively vesicular and porous it constitutes *pumice*. The other acidic volcanic rocks are the *phonolite* group. Phonolite is a dark greyish compact slaty rock, which derives its name, and also its popular name of clinkstone, from the ringing sound which it gives out when struck by a hammer. It may be porphyritic, vesicular, or amygdaloidal; and, like the rest, its composition is very variable.

Owing to the complexity and variability of these volcanic rocks, it seems impossible to make a thoroughly satisfactory classification. Varieties of rocks which pass under the same name may differ more from one another than from some of the members of another group, whether we regard their texture or composition. Names which were given to rocks a generation ago, based on some superficial character, have been found to be inappropriate when their composition has been investigated; and in all directions rocks of intermediate characters are met with which might more or less appropriately be placed in one group or another.

(*b*) *Plutonic rocks.* This division of the igneous rocks comprises all those which, from their position, mode of occurrence, and texture, suggest the idea that they have been solidified at a depth below the surface of the earth. There is no essential difference in composition between them and the volcanic rocks, especially as regards their elementary constituents, though frequently these constituents have not combined so as to form identically the same minerals. The type of the plutonic rocks is *granite*, a rock which has been already frequently alluded to and to some extent described. It is undoubtedly the most important and abundant rock in the earth's crust. It not only apparently underlies all the rest, but it forms a considerable portion of the surface of the earth.

It presents, however, no appearance of having cooled on the surface, being always granular and crystalline, and the masses at present at the surface have no doubt been exposed by the denudation of overlying rocks. The crystals of granite are closely packed together, generally in a matrix of transparent quartz, and there is never any cementing material as in the sedimentary rocks. The silica of the quartz, together with that which is in combination as silicate in the felspar, mica, or other minerals, constitues from 62 to 81 per cent. of the whole weight, so that granite belongs to the acidic class. The mica may be replaced by chlorite or talc, when the rock is called *protogine* ; or by schorl, when it is called *schorl granite*, or *luxullianite*. The presence of hornblende in addition to the ordinary constituents forms *syenitic granite*.

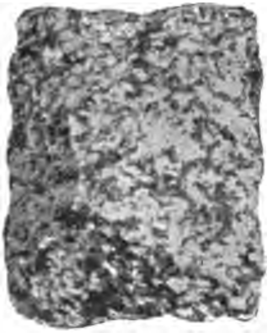
Fig. 35.—Granite.

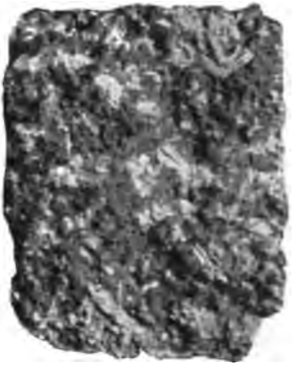
Fig. 36.—Porphyritic granite. *i.e.* granite with large felspar crystals.

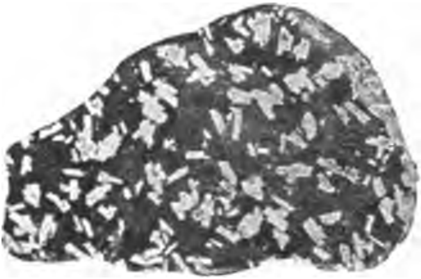
Fig. 37.—Porphyry.

Granite porphyry is a rock having a compact granitic matrix, rich in felspar, with distinct. embedded crystals of felspar, quartz, and mica. *Quartz porphyry* is somewhat similar to granite porphyry; but it has no mica visible, though the chemical constituents of mica are present. *Felsite* is practically a fine compact granite without visible crystals; and *pitchstone* is of the same composition, but vitreous in texture. It is a lustrous rock, breaking with a smooth conchoidal fracture like glass; but when examined microscopically small embedded crystalline particles can be distinguished. These four last-mentioned rocks are no doubt derived from the same material as the true granite, the differences being chiefly in texture, caused by varying conditions of cooling.

The *basic* plutonic rocks are mainly admixtures of felspars with hornblende, augite, or mica. Sometimes they contain chlorite, iron oxides, etc., but quartz is exceptional. They contain more hornblende than the basalts, but otherwise they greatly resemble them, and are no doubt their plutonic equivalents; the chlorite and other accessory minerals having in all probability been developed by internal chemical changes subsequent to their solidification. The most important group is formed of those which are often designated *greenstones;* namely, *diabase*, *gabbro*, *diorite*, and *aphanite*. They all occur as dykes and veins, chiefly in the more ancient rocks. Their green colour is derived partly from their hornblende, and partly from a small quantity of chlorite which is generally present. Gabbro is coarse-grained, diabase and diorite are fine-grained, and aphanite is very compact and fine-grained. They are all occasionally "amygdaloidal"—that is to say, they contain vesicular cavities which have been subsequently filled in by other minerals. They are, no doubt, all varieties of the same rock, solidified under slightly different conditions.

The only other basic plutonic rock which need be mentioned is *syenite*, a crystalline mixture of felspar and hornblende. The name is derived from Syene in Egypt, though the rock of Syene is a syenitic granite according to the most usual terminology. Syenite forms large masses in Saxony and Transylvania, and it also occurs in Charnwood Forest in Leicestershire.

III. METAMORPHIC ROCKS.

All rocks have undergone some amount of change since their original deposition or solidification, but the term metamorphic is only applied to those in which extensive chemical and physical changes in the rock itself have caused the formation of new compounds, or have brought about a rearrangement of the mineral constituents. It will be most convenient to divide these rocks into two divisions, the first containing those rocks which are not altered beyond the possibility of recognizing their original condition, and the second those that are so altered by chemical and other changes that their primitive state is quite obliterated.

(*a*) Of the less-altered class, *slate* or *clay slate* is the most common. It is evidently a sedimentary rock deposited in the usual way by water, as is clearly shown by the presence of occasional bands of gritty material. Very little chemical action has occurred in slate, the chief alteration consisting in the development of cleavage planes, almost invariably across the planes of bedding. This enables the rock to be split into thin sheets for roofing, etc. The rock consists of indurated argillaceous material, though some of the older slates are made up largely of mica. Some slates are calcareous, and are called *marl slates*.

Marble is limestone altered by the whole mass becoming crystalline. This has caused the fossils to entirely disappear, while the mineral impurities present in the limestone have caused the various streaks and blotches of colour which adds so much beauty to many marbles.

Quartzite is another rock which may be conveniently placed in this division, though its mode of origin is rather obscure. It looks as if it were a sandstone which had been half melted so that the grains of quartz have run together and formed an exceeding hard rock, but it is most probable that in most cases it is a sandstone cemented together by an aqueous deposit of silica.

(*b*) The second division comprises the class which is more properly called metamorphic. These rocks constitute the oldest and most rugged parts of Great Britain, viz. Wales and the Highlands of Scotland. They are obviously stratified, but there is no known agency at work on the earth's surface which seems capable of producing them. Some have fancied that they may perhaps be the very earliest of the aqueous rocks which were thrown down at a time when the ocean was intensely hot, and when terrestrial conditions were very different from the present; but it is not at all likely that such a large amount of the very earliest strata would have been preserved. In all probability they are rocks which have been deeply buried in the earth, and under the influence of subterranean heat, combined with great pressure and the presence of water, have undergone chemical and physical changes which have entirely disguised them. The changes are twofold. They are "foliated," or "schistose;" that is, as has been already explained, they consist of an alternation of thin flaky layers of such mineral substances as are found in igneous rocks in a crystalline condition, sometimes lying more or less smoothly one upon another, but generally very much convoluted and crumpled. Sometimes, especially when mica is one of the materials, the folia in a sample can be easily separated from one another with the point of a knife, and the piece of rock split up; but in other cases this cannot be easily done, although the layers can be readily distinguished. From these characters they are often called the "crystalline schists." Another change which appears to have often occurred is the development of new minerals in the substance of the rock from materials derived from some of its original constituents, or possibly sometimes brought into it by slowly percolating water.

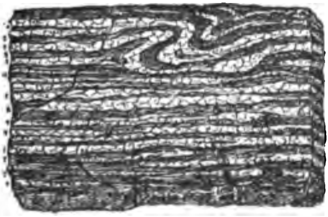
Fig. 38.—Foliated rock. A specimen of gneiss with thin layers of felspar, quartz, and mica.

The most abundant rock of this class is perhaps *gneiss*, a rock which consists generally of precisely the same constituents as granite. It may not at first appear possible that such a rock could by any chemical process be evolved from any known aqueous rock, but we must remember that, if the generally accepted theory of a once molten earth be true, all our aqueous rocks have been derived from rocks originally igneous. A clayey micaceous sandstone, with its accompanying accidental impurities, has often all the elements in it which would be necessary for the manufacture of gneiss; and it is thought quite possible that such a rock, placed under the conditions described above, might be converted into gneiss. At the same time, when we consider that mineralogically granite and gneiss are identical, the question naturally arises as to whether under any circumstances granite could be converted into gneiss and gneiss into granite; or whether each of them could, under different conditions, be got from the same original magma. Observed facts favour the idea that this could be the case, as granites are observed to become schistose in parts, and gneisses granitic. No chemical or microscopic examination of a specimen will enable one to say whether it is an altered form of granite or of some sedimentary rock, this can only be decided by an examination of its mode of occurrence. If it is bedded, it is almost certainly an altered aqueous rock; if irruptive, or if continuous with a mass of granite, it is of igneous origin. In this latter case we ought not properly to call it a metamorphic rock. By variation of the relative proportions of the essential, and by the introduction of accessory minerals, combined with differences of texture, a large number of varieties of gneiss are produced, such as porphyritic gneiss, slaty gneiss, syenitic gneiss, etc.

The other schistose rocks are the schists proper, the best known being *mica-schist.* This consists of quartz and mica, the proportions varying greatly. Garnet is common as an accessory mineral, small reddish-brown garnets being exceedingly abundant in the schists of the Scotch Highlands. With chlorite instead of mica we have *chlorite-schist*, and similarly also *hornblende-schist*, *talc-schist*, and others, with every possible intermediate variety. These rocks are frequently interbedded with altered limestones and other stratified rocks, and are doubtless produced from sandy and argillaceous deposits, the relative amount of either ingredient determining the character of the schist. The quartz of the sand is but little altered; the clay with its impurities is converted into mica, hornblende, talc, etc., as the case may be; while any subordinate materials embedded in or with the original rock, such as ironstone, or coal, would be changed into ferruginous schist or graphite respectively.

The history of the metamorphic rocks is, however, wrapped in much obscurity, and will be further considered in connection with the internal heat of the earth.

SUMMARY.—The texture of **igneous rocks** depends on conditions of cooling. They may be coarsely, finely, or partly, crystalline; glassy; loose in texture; amygdaloidal; and may at the same time be similar or different in mineral and chemical composition. They consist of a limited number of essential binary compounds, and it is possible that these have combined to form various minerals under the influence of varying conditions of pressure and temperature. If they contain less than about 60 per cent. of silica they are termed *basic;* if more, *acidic.* They are classified thus:—

1. *Volcanic* rocks, solidified at or near the surface, such as lava and volcanic tufa.
    (1) *Basic:* basalt, dolerite.
    (2) *Acidic:* trachyte, obsidian, pumice, phonolite.
2. *Plutonic* rocks, solidified deep down from the surface.
    (1) *Basic:* aphanite, diabase, diorite, gabbro, syenite.
    (2) *Acidic:* granite of various kinds, protogine, granite-porphyry, quartz-porphyry, felsite, pitchstone.

Metamorphic rocks are rocks which have undergone extensive changes since their original formation. They have—

(1) *Original condition still recognizable:* slate, marble, quartzite.
(2) *Original condition obliterated:* gneiss, mica-schist, chlorite-schist, hornblende-schist, talc-schist.

QUESTIONS.

1. Explain how the texture of igneous rocks is accounted for, with examples.

2. What explanation can be given of the varying mineral composition of igneous rocks if they are all derived from the originally fluid mass of the earth?

3. Upon what twofold basis are igneous rocks classified?

4. What is the difference between (1) basalt and trachyte, (2) granite and syenite, (3) dolerite and diorite?

5. Define *metamorphism;* and describe the nature of the changes which have taken place in marble, quartzite, and gneiss respectively.

CHAPTER VI.

ON THE INDUSTRIAL USES OF ROCKS.

Having studied generally the composition, properties, and classification of rocks, it will, perhaps, be convenient now to consider the various uses to which they are put in building and other works. The hard rocks are quarried for building material, the soft ones are used in brick-making, and are important elements in mortars and cements.

Sand is not employed much directly in building. It is to some extent mixed with a cementing medium and moulded into blocks, and it is used in making mortar. Pure siliceous sands, obtained from the tertiary and lower greensand strata, are used in glass-making; loamy sand is used for making moulds for casting; sands consisting of tiny siliceous shells are used in the shape of Bath brick and rotten-stone for scouring; and other calcareous shelly sands are employed as manure in Cornwall and other parts.

Clays are much more important on account of the millions of *bricks* which are made from them every year in England. A good brick clay consists of a fine and intimate mixture of clay and sand. If coarse or pebbly it is made fine by mixing with water, running off, and settling. It should be moderately free from alkali, lime, and iron, as excess of these will cause the bricks to run when heated. Iron, however, is always present to some extent, and, combined with judicious firing, is the main cause of the various colours,—about 2 per cent. being sufficient to give a dark-red brick owing to the formation of iron peroxide.

A sandy clay, very free from the above-named impurities, yields *fire-brick*, and the presence of a little carbonaceous matter seems to improve it, as the best fire-clays are those which underlie the beds of coal, and which contain fossil vegetation. The best known fire-clay is that of Stourbridge. It is used for lining furnaces and gas retorts, and for making crucibles and other appliances exposed to intense heat.

The finer and purer clays are used for *earthenware* and *porcelain.* The clay employed for common earthenware may contain about 7 per cent. of various impurities, while porcelain clay does not exceed 1 per cent., and is practically infusible. The best porcelain clay, or kaolin, is obtained from decomposed granite. The cause of this decomposition has been already explained. Sometimes the clay so formed remains mixed with the residual quartz and mica, and must then be washed out, but often the washing has taken place naturally by the action of rain and streams, and a large clay deposit formed in the lower part of a valley. Clay of this kind is obtained at various points round the granite areas of Cornwall and Devonshire. *Fuller's earth* has been alluded to; it is obtained in several localities from the lower greensand, and in the south of England.

Mortar is a mixture of lime and sand. The lime is obtained by heating to redness carbonate of lime in the form of marble, limestone, or chalk. If there is very little impurity present, the lime is technically called "rich" or "fat." When water is added to it it at once gets hot, steams violently, and falls to powder, when it is said to be "slaked." To convert slaked lime into mortar more water is added, and also two or three times its weight of sand, and the whole well mixed. When used, mortar undergoes two changes. In the first place it loses its superfluous water, either by evaporation from its surface, or by absorption into the brick or stone. This is called "setting." After it has set it begins to absorb carbonic acid from the air. This unites with the lime and forms hard carbonate of lime, which, after a long period, becomes crystalline and very hard. This process takes place on the outside first, and gradually spreads inwards; but at an increasingly slow rate, as it has been found that the internal parts of the mortar employed in the pyramids still contain free lime. It is doubtful whether the sand has any chemical action. Its chief use seems to be to make the mortar rather more porous, so as to admit the air, and to form nuclei around which the hardening process can extend. As this final hardening cannot occur till the mortar is dry, and unless air has access to it, it is obvious that mortar is unsuitable for use under water.

If, however, the carbonate of lime is mixed naturally or artificially with clay, and then heated and powdered, a material is obtained in which the chemical action is quite different, and is altogether independent of the presence of air. Such a compound is called, according to its composition, a *hydraulic lime*, or *cement*. The action of the clay on the lime when it is heated is said to be as follows. At a certain temperature the clay (silicate of alumina) and carbonate of lime react on each other; carbonic acid is liberated, and the silica of the clay unites with some of the lime, forming silicate of lime. At a higher temperature the alumina unites with another portion of the lime, forming aluminate of lime. The silicate of lime and aluminate of lime then unite together to form a double salt, viz. silicate and aluminate of lime. If sufficient clay is present in the first instance, *i.e.* about thirty per cent., there will be now no free lime left, and when water is added it will merely wet the powder without any production of heat or slaking. But the water enters into chemical combination with the double salt, and quickly forms a very hard dense mass of great strength and durability, and the advantage of this material is that it can be used under water for harbour works and breakwaters, where ordinary mortar, for the reasons given, would be quite inadmissible. Cement is chiefly used in making concrete, by mixing with it broken stones, gravel, or shingle, and allowing it to set into a compact mass of conglomerate.

The chief natural mixture employed in cement-making is the septaria of the London and other clays. These are either dug out of the clays, got out of the cliffs or on the beach, or dredged up from the sea bottom, and require no further admixture. The cement made from them is called "Roman" cement. In more recent times the method has arisen of mixing the materials artificially. This is carried on along the lower portions of the Thames and Medway, where there is an abundance both of chalk and of calcareous mud. These ingredients properly mixed are calcined at a high temperature, and sold under the name of Portland cement.

If after calcination some lime remains uncombined, the product is called a *hydraulic mortar*. It presents a faint appearance of slaking when water is added, but still has hydraulic properties, *i.e.* will set independently of the air.

These cements have come very largely into use in recent years, not only for the large works described, but for manufacturing paving slabs and ornamental stones of various descriptions. By mixing finely powdered red brick and other materials a red stone is obtained, which presents some advantages over terra cotta, and is coming largely into use for decorative purposes.

When gypsum is heated to a temperature of 120° C., a white powder, called *plaster of Paris*, is obtained. The gypsum consists of sulphate of lime, chemically combined with water. The latter substance is driven off by the heat and the simple sulphate left. On adding water to it, and mixing it up into a thin paste, the two substances re-unite and again become hard. As at the time of hardening there is a slight expansion, it forms an excellent material for casts. Its chief use is for plastering walls and ceilings, and for interior ornamentation. It is quite unsuited for outdoor work, as it is slightly soluble. When weak glue is used instead of water, the result is called *stucco*, and is capable of receiving a high polish. When alum is ground up with it, it is called *Keene's cement;* with borax, it is *Parian cement.*

The hard rocks are employed largely for building; but also for paving and roofing, road-making, architectural ornament, and for statuary, according to their special properties.

For building purposes, the most valuable property a stone can possess is power to resist exposure to the weather; but other elements have to be considered, such as strength, appearance, ease of working, and easy access. With regard to resisting power, much depends on the climate to which the material is to be exposed. Almost any stone will wear well in the dry, equable climate of Egypt, while few can resist the variable climate of England. A building-stone is exposed to the chemical and mechanical action of the atmosphere. A dense, hard, crystalline stone generally wears well, because it does not permit the air and moisture to penetrate into it like one which is loose and porous. When a stone readily becomes saturated with water, it is very liable to become disintegrated, owing to the expansion of the water when it freezes. In this way the constituent particles are forced asunder, and, their cohesion being overcome, they form a loose, crumbly layer on the surface of the stone, which, especially after a frost, falls as powder. But the water acts chemically as well. The air contains carbonic acid, and, in towns especially, sulphurous and other acids; and these, dissolving in the falling rain, are carried by it into the recesses of the stone, where they attack and render soluble the carbonate of lime and other matters. In this way the solid mass of limestones, and also the cementing material of many of our sandstones, are dissolved and washed away. It is evident therefore that, especially in the case of large and costly buildings, the selection of a suitable stone is of the utmost importance. It should be remembered also that the air of our great modern manufacturing towns is much more detrimental to buildings than it was in the comparatively small towns of olden times, and that, therefore, it does not follow that a stone which has worn well under mediæval conditions will be suitable for a town edifice at the present time. A striking illustration is afforded of this fact by the Houses of Parliament. A royal commission, after inspecting quarries and examining stones all over the kingdom, came to the conclusion that the most suitable stone was the magnesian limestone, and recommended its use. Their recommendation was adopted; but before the building was finished the stone began to decay in an alarming fashion: yet there are churches and other buildings in Nottinghamshire and other parts built of this stone which have been standing for hundreds of years, and have worn well. Another fact, however, which is necessary to bear in mind in selecting any building-stone is this—that in the same quarry one layer of stone may be good, and another bad, owing to some slight difference of texture; and a stratum which consists of good durable stone in one place may degenerate into rubbish in the course of a few hundred feet. It is really necessary, therefore, that every piece of stone should be inspected; and if this can be done in the quarry itself, so much the better. In placing the stone in position the blocks should, wherever possible, be laid in the same manner as they were in the quarry. The reason for this is, that stones are often laminated, and are much more liable to split parallel to the planes of bedding than in any other direction; and consequently, if the block is placed upright, water can readily get down between the laminæ, and, in expanding, will split them off one after the other; whereas, if the laminæ are in their natural horizontal position, this cannot happen.

Many attempts have been made to prevent the disintegration of building stones, the objects aimed at being the keeping out of the water and the introduction of an insoluble siliceous cement which will keep the particles together; but none of the processes tried appear to be thoroughly satisfactory.

It is very desirable that a building-stone should be of a pleasant tint as well as durable. A cream colour, such as is possessed by the magnesian limestone and the Portland and Bath stones, seems most in favour, or the pale reds of some of the New Red Sandstones. Some stones have also the useful property of being soft when first got out of the quarry, but becoming much harder on exposure to the air. The lower stones of a great building or other structure have often to bear an enormous downward pressure or "crushing weight." Stones vary much in this respect, but nearly all are strong enough for ordinary purposes, being capable of withstanding a pressure of from two thousand to twenty thousand pounds per square inch, hard stones, like granite and slate, being the best. The weight of the stone is another consideration. The heavier it is, the more compact and durable it is, as a rule. Some of the loose, sandy, and calcareous stones weigh less than 120 pounds to the cubic foot, while the granites exceed 160.

For ornamental purposes, especially for statuary, an even texture is of the utmost importance, as the unexpected occurrence of a cavity, concretion, or fossil would quite spoil a work of art.

The British Isles contain a large variety of granites, differing much in durability and appearance. The porphyritic and other granites of Cornwall are largely used for docks and breakwaters. Among the more handsome granites are those of Shap, to be seen in the posts round part of St. Paul's Cathedral, and the red granite from the Ross of Mull, which forms the columns of Blackfriars Bridge, and which was employed hundreds of years ago in the building of the Monastery of Iona. The schorl granite, or Luxullianite, of Cornwall is a noticeable stone, and was used in the construction of the Duke of

Wellington's sarcophagus, to be seen in the crypt of St. Paul's. The granites of Aberdeen and Peterhead are sent to many parts of the world, and the former town is largely built of it. St. Petersburg contains many public and private buildings built of granite from Finland. The Egyptian granite is syenitic, and has been used in the obelisks, including Cleopatra's Needle on the Thames Embankment. These stones still retain, almost unaltered, the hieroglyphs cut in them four thousand years ago. In Leicestershire the granite of Mount Sorrel, the syenite of Charnwood, and the felsite of Bardon Hill, are largely used for road material, and, to some extent, for building.

Of other coarse-grained rocks, the *porphyries* are employed in ornamental work on account of their beautiful colours and capacity for taking a high polish. The "rosso antico" of mediæval Italy is an Egyptian porphyry of high repute. *Serpentine* is valued for the same reason as porphyry, but it is only suitable for indoor work, as it cannot stand the weather. The Lizard serpentine is largely used in churches, for fonts, pulpits, and small pillars. The "verde antico" was a green serpentine used by the Romans. Serpentine has been employed, in conjunction with Carrara marble, in the exterior of Florence Cathedral, but it is much decayed. *Alabaster*, *malachite*, *fluor*, and other spars are used for decorative work.

Basalt is not suited for building, as it is difficult to obtain in large blocks, and is too sombre in appearance. It is used for road mending; and basaltic columns may be seen along the Rhine, used as posts.

Marbles are either white or variously coloured. The best white marble was formerly obtained from the Island of Paros and from Attica, and the abundance of this beautiful material no doubt had a stimulating influence on Greek art. Most of the great temples and statues of Greece were made of it. The Carrara quarries, near Spezzia in Italy, have also been noted for their beautiful marble from ancient times till the present, and are now practically the only source of the best white statuary marble. The antique statue known as the Apollo Belvidere is made of it, and so are the great works of Canova. Hundreds of quarries exist in the district, but only some fifty are worked, and only a few yield the pure white marble.

This marble is granular, and exceedingly pure, containing 99 per cent. of pure carbonate of lime. We have many marbles in the British Isles, but they are all coloured. Black marbles are found in Derbyshire and Kilkenny, and coloured ones in Devonshire. Many of our so-called marbles, however, are limestones. The Purbeck and Sussex marbles consist of a greyish blue matrix, with paludina shells embedded in it. A fine collection of European and Algerian marbles may be seen in the entrance hall of the National Gallery in Trafalgar Square, and also at the Holborn Restaurant.

Of *sandstones*, those with a siliceous matrix are the most durable. The Craigleith stone, which is much used in Edinburgh, is of this kind, and is an excellent building material. Dark red sandstones, from the Old Red system, are largely used in Dundee, but are too gloomy, though they wear well. Tintern Abbey is built of the same kind of stone, and has stood since the thirteenth century. The celebrated Scone stone, now and for many years in Westminster Abbey, is an Old Red Sandstone boulder. The Yorkshire sandstones, derived from the millstone grit and other formations of the Carboniferous system, are many of them fine-grained and durable, and are largely used in the great manufacturing towns, which have hardly any brick buildings in them. The "New Red" sandstones consist of grains of silica cemented by carbonates of lime and magnesia. Some are white, and some red. Many of the latter look very well, but wear badly. The town of Penrith and Furness Abbey are built of them, and they are largely used in Liverpool. Cologne Cathedral is built of a sandstone of this age, as are also the English cathedrals of Worcester and Chester, but the latter is much decayed. Sandstones resist the chemical action of the atmosphere exceedingly well if they have a siliceous cement; but with a calcareous or ferruginous cement they are not to be relied on. Kentish rag is a calcareous sandstone of the Lower Greensand formation, which is used somewhat in the towns of north and mid Kent, and to some extent in London, but it is very variable and often shelly.

Limestone is, perhaps, the most popular building material in England. It is pretty widely spread, and is easier to work, and therefore cheaper than sandstone. It is largely used in

London, the limestones of the Oolitic system being in most request. They are uniform in texture, have a good colour, and harden on exposure. The Portland stone is the best of all, being hard, very slightly absorbent, and durable. It is, however, somewhat uneven, the presence of large shells unfits it for delicate work, and it is dearer than the rest. St. Paul's, in London, and Salisbury Cathedral are good examples of its use. Bath stone is handsome, easily worked, and cheap; but not durable. It has been used for the interior of St. Paul's, for Bath Abbey, and Lincoln Cathedral. It is a very absorbent stone, being capable of soaking up eight and a half pints of water to a cubic foot of stone. Caen stone is something like Bath stone, but harder and less absorbent. It is an Oolitic stone quarried in Normandy, and was introduced into England by the early Norman architects. It may be seen in the front of Buckingham Palace, in Canterbury Cathedral, and in Westminster Abbey. Another Oolitic stone, the Barnack stone, has been used a great deal in Cambridge and in many old churches in the neighbourhood, and stone from the Coralline oolite has been employed in many of the Oxford colleges with disastrous results. The Oolitic system in Germany furnishes a remarkable fine-grained even-textured stone used for lithographic printing. The Mountain Limestone of the Carboniferous system is a hard durable stone, but is not largely employed for building, perhaps on account of the excellence of the carboniferous sandstones.

Magnesian limestone is a favourite building stone, but it does not appear to stand the atmosphere of great towns well, and is a risky stone to use, on account of its very great variability. It is best when it is crystalline and contains a little silica, and when the two ingredients are mixed in the proportion of one molecule of carbonate of lime to one molecule of magnesia (50 to 42). Beverley Minster is built of it, the Jermyn Street front of the Geological Museum, and, as has been already mentioned, the Houses of Parliament.

Slates depend for their value on their cleavage. The best slates are hard, fine-grained, and cleave into thin plates, some not exceeding one-sixteenth of an inch. They stand the weather perfectly, and are quarried almost entirely for roofing purposes, in enormous quarries in North Wales, Cornwall, Argyllshire, and in South-west Ireland. On account of their lightness, thinness, and cheapness, they have very largely displaced other roofing materials all over the country, and the picturesque high-pitched roof of red tiles is becoming a thing of the past. From the practical point of view, however, there is no doubt of the superiority of slates.

SUMMARY.—1. Rocks both hard and soft are utilized for buildings, the latter for bricks and as accessories in mortars and cements. *Sand* is also used for glass, moulds, and scouring; *clay* for bricks, earthenware, and porcelain.

2. *Mortar* is slaked lime mixed with sand; *cement* is made by mixing chalk and clay in certain proportions, and then heating them. This, when powdered and mixed with water, sets very hard even under water, being, unlike mortar, quite independent of access of air. Gypsum when heated yields *plaster of Paris*, *Keene's cement*, and *Parian cement*.

3. The most desirable properties in a building stone are weather-resisting power, strength, and a good appearance. Changes from wet to dry, frost, and acid fumes are most injurious to stone, the latter particularly to limestones.

4. The most noteworthy building and decorative stones are the *granites* of Shap, Mull, Cornwall, Aberdeen, Finland, Egypt, etc.; *porphyry*, *serpentine*, *alabaster*, *marbles* of Carrara, Devonshire, Derbyshire, etc.; *sandstones* of Craigleith, and of the Carboniferous, Old Red, and Triassic systems in great variety; *limestones*, especially Oolitic, such as Bath, Caen, etc.; *magnesian limestone*, *slates*.

QUESTIONS.

1. What characters are necessary in a good brick earth? What is a *fire-brick?*

2. What is the origin of the best porcelain clays? Where are they found?

3. Describe the chemical action which accompanies the hardening of (*a*) mortar, (*b*) Roman cement, (*c*) hydraulic mortar.

4. What is plaster of Paris? and what other "cements" are made from it?

5. Discuss the relative value of sandstones and limestones as building materials. Why have the ancient Greek and Egyptian temples stood so well?

6. Describe the special characters of serpentine, Portland stone, Bath stone, magnesian limestone, and slate.

CHAPTER VII.

THE WEATHERING OF ROCKS—SOIL—AGRICULTURAL GEOLOGY.

THE whole of the earth's surface is in constant contact with the air, and the greater portion of it is more or less frequently wetted by the rain. By the influence of the air and the rain many important modifications occur in the exterior portions of the earth's crust. Their mode of action has already been briefly referred to, and may now be regarded more closely. The air is a mechanical mixture of two gases, nitrogen and oxygen. Both are elements: the former is very inert and passive; the latter is very active, and always ready to act upon and combine with many other substances. There is also present in the air, as an impurity, variable quantities of carbonic acid. This, like the other two, is invisible and colourless. It is derived from the decay of organic matter, the burning of substances containing carbon, the breathing of animals, and in some other minor ways. There are many other substances present in the air as well, such as aqueous vapour and compounds of nitrogen and sulphur. As the water in the rocks sinks downwards, the air, with all its contents, is drawn down into the rocks and fills all the spaces vacated by the water, and it is in this way brought into very intimate contact with a considerable portion of the upper layer of the earth's crust. Whenever rain falls it brings down with it a portion of the carbonic acid and any other soluble constituents of the air, and as it sinks down through the soil it takes up still more from the decaying vegetable matter it then meets with. In this way it becomes a weak solution of carbonic acid, and in this condition is able to bring about changes which it is quite unable to cause when pure. To illustrate the power of carbonated water a little precipitated carbonate of lime may be stirred up with pure distilled water so as to make it slightly milky-looking from the particles of carbonate of lime suspended in it. If now some carbonic acid is bubbled into the water it will gradually get clear, showing that the suspended matter is dissolved. If, however, the water is now boiled so as to drive off again all the carbonic acid, the water will again become turbid, showing that without the help of the carbonic acid it cannot keep the chalk in solution. Now, this power of dissolving carbonate of lime which is possessed by carbonated water is of very great importance in nature, because by its agency all rocks formed of or containing this compound are slowly destroyed, both on the surface and below ground. By this power most of the great caves of the world have been formed, and the great masses of stalactite, stalagmite, and travertine deposited whenever, for any reason, the water has lost some of its carbonic acid. This happens whenever the water is exposed to the air: while the carbonated water is percolating through the hidden recesses and crevices of the rocks, it dissolves; but when it is exposed to the free action of the atmosphere, either in the open air or in a cave with a current of air through it, it begins to deposit. We are, however, just now more concerned with what is going on at the surface, and may take as an instance the chalk country of the south-east of England. About 96 per cent. of the chalk is pure carbonate of lime, the remainder being clay and other more or less insoluble matter; and, in addition, there are the nodules and masses of flint. Under the action of the air and rain the carbonate of lime slowly dissolves away, and there remains undissolved the clay and the flints. This clay, with flints, constitutes the natural soil of the chalk country. It is very similar with our limestone regions. In the elevated and exposed limestone tract of the West Riding of Yorkshire curious examples of the corroding power of carbonated water may be seen. The surface of the limestone is here often washed quite bare of soil, which is carried down to lower ground, and this bare surface is corroded into labyrinthine channels, along which the water flows and often works its way down to lower levels in the rock, when it runs through the joints and fissures and forms the caves which abound in this region. On the faces of many of the limestone cliffs the fossils may be seen to stand out in bold relief, because, although also generally carbonate of lime like the mass of the rock itself, they are crystalline and consequently harder, and so resist the action of water while the rest of the rock is dissolved more freely. Many limestones which when broken hardly seem to have any fossils in them, are seen to be full of them when thus "weathered."

Still more remarkable is the action of carbonated water upon granite and basalt. The felspar of these rocks generally contains potash, soda, or lime, as has been already explained, and this when attacked by the carbonic acid is converted into a soluble carbonate, which is readily carried off, and a residue of clay left. This action often extends to a great depth in granitic areas, and converts what was originally a hard rock into a disintegrated mass of clayey gravel, whose origin can often only be recognized by the occurrence in it of lumps of unaltered granite, and by the fact that, if followed downwards, sometimes as far as thirty or forty feet, it is found to pass imperceptibly into unaltered granite. Cases of this are quite common in Dartmoor, Brittany, Germany, and in all parts of the world where there is granite. This clayey gravel represents the natural soil of a granite district. Basalt suffers in the same way. A case may be seen on the moors in the North of Yorkshire, where a great vertical dyke of basalt about twenty yards thick runs across Eskdale towards the sea. In many places it looks like a gritty clay containing nodular masses of greyish-coloured stone. On examining these nodules they are found to be more or less soft and decomposed on the outside, and to pass gradually into a hard nucleus of unaltered basalt.

The water which percolates through the granite and basalt often bears away, not only the alkaline carbonate in solution, but, also in suspension, a good deal of, and sometimes all, the clay. This indeed is, no doubt, how nearly all our clays have been formed in the first instance. If the clay is pure silicate of alumina, without any iron oxide or other colouring matter, it forms the best porcelain clay; but most clays contain much foreign material, some, such as compounds of lime, magnesia, iron, manganese, derived from other silicates in the original igneous rocks, and others owing to their having undergone many changes since they first emerged from their native felspar.

Both in the water, and also directly in the air itself, the oxygen acts on various substances in the rocks, and brings about many changes. Compounds of iron are very abundant in the rocks, and are often acted on by oxygen and converted into other compounds. Thus carbonate of iron is often present in rocks, and under the influence of oxygen loses its carbonic acid and is converted into peroxide which, when hydrated, gives a red or yellow colour. This accounts for many rocks being red outside and colourless a little way in. Iron pyrites and silicate of iron undergo a somewhat similar change; in the latter case the green silicate is often converted into reddish-coloured oxide. Deposits which are dark in colour owing to the presence of carbonaceous matter are bleached by the oxidation of the carbon. Many other instances could be given of the changes which almost all rocks undergo under the influence of the air and rain. From what has been said it is obvious that, in collecting specimens of rocks, care must be taken to secure unaltered samples; although it will be very instructive to take a weathered sample as well, for the sake of comparison.

Changes of temperature in the air cause the rocks to split to pieces. Many extreme and striking instances of this are recorded by travellers and explorers, both in hot and cold countries. Heat causes rocks as well as other things to expand, and cold causes them to contract; and as it is the outside which experiences the greatest changes, it is very apt to crack and split off from the inner portion. The bare splintered crags which form the summits of many of the almost inaccessible Alpine peaks have been formed in this way. During the day they become warmed, and the intense cold which follows the sunset causes rapid external contraction and fracture. Their bases are often found to be buried in the fragments chipped off. The foregoing action takes place when the rocks are quite dry; but when

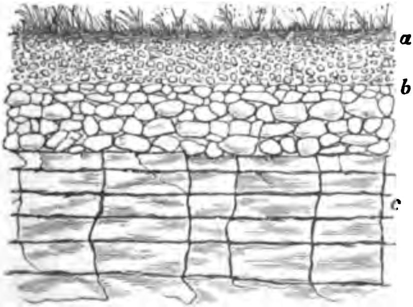

FIG. 39.—Rock passing upwards into soil.

they contain moisture, as they nearly always do, the disintegrating action caused by the expansion of the freezing water is still more marked.

By these various processes the bare rocks get covered with loose disintegrated material derived from their own waste, and this material forms the groundwork of the soil in which things grow. Decaying vegetable and animal matter enriches it, and renders it still more suitable for plant life. Over most of the world it is continually being removed by the rain which runs off it, and it is as continually replenished by the breaking up of the rock below and the decaying vegetation above. The upper portion in which organic matter predominates is carried down by rain, and the lower and more mineral portions are brought to the surface by burrowing animals such as the mole and rabbit, and particularly by the earthworm, who goes below and fills himself with soil for the sake of the nutriment it may contain, and then comes to the surface and ejects it, forming the well known worm-like casts of mould so common on lawns and meadows. Leaves and other matters are also drawn down into the soil by the same agency, and the burrows which they leave admit water and air to the soil. Thus the inorganic and organic matters are continually being intermingled and the soil improved. This loosening and breaking up of the hard crust of the earth and its conversion into soil may be compared to the rusting of a metal, though the process is much more complex, and the soil may be regarded as the rust of the solid earth. This rock-weathering process is the first stage in the round of changes by which old rocks are pulled to pieces and built up into new ones, the new ones to be themselves again treated in the same manner. Thus the solid earth, which seems so fixed and permanent, is in a state of constant change.

Before considering the soil in its relation to agriculture, there is the effect of wind to consider. This is the mechanical action of the air as distinguished from the preceding or chemical action. Many hundreds of square miles of land are covered by sand blown over the land from the seashore or from sandy deserts. The coast of North-east France and of Belgium is fringed by a range of sand-hills which cover and render useless for agriculture a long strip cf land. A still larger sandy region, known as the "Landes," has been similarly formed along the shores of the Bay of Biscay, between the Gironde and Pyrenees. These sand-hills, or "Dunes," are advancing inland at from three to six feet annually. Portions of North Wales, in the neighbourhood of Rhyl, are being encroached on by fine sand blown inland from the seashore; and the same is the case in some parts of Norfolk. One of the difficulties in connection with the Suez Canal is the sand which is continually blown into it from the desert, and which necessitates a large annual expenditure in dredging to keep the canal open. This continual advance of sand over a country, under the action of the prevalent wind, may be likened to the advance of a glacier, and is quite as irresistible. Many fertile tracts have been utterly ruined and estuaries choked up by it; as, for example, that of the Dee, near Chester. The only thing which can be done to prevent it is to encourage the growth of coarse vegetation, which will bind the sand together by its roots and thus prevent it from being blown any further; but this is often impossible, owing to the rapid movement and the continual arrival of fresh supplies of sand, which bury the vegetation. Another peculiar effect of the wind, in causing a drift of sand and shingle along the shore, will be considered in connection with the sea.

Sand is, for the most part, composed of small pieces of silica, often sharp and angular, and, as they are very hard, they cut and scratch any rocky surface they may be blown against. This property of sand has been put to practical use in what is called the "sand blast," where a stream of sand is ejected with great force against the surface of glass to produce a frosted appearance. If a thin sheet of metal with a pattern cut out in it is placed over a pane of glass and the sand blast directed against it, the grains of sand will chip out little pieces from the glass wherever it is not protected, and so produce a frosted pattern. If the blast is allowed to continue for some time, it will cut a hole quite through. A similar action occurs in nature when sand is blown by the wind. Overlooking the Nidd valley in Yorkshire there is a great rocky platform, which in one place has been curiously worn by the air and rain into a number of great masses of rock completely separated from each other. The rock is a coarse sandstone known as "millstone grit," and lying about the bases of the rocks there is a quantity of gritty sand formed by their disintegration. The locality is high and exposed, and consequently windy, and this sand is perpetually blown to and fro, and rubbed against the bases of the rocks. The consequence is that all of them have become very smooth, the bases get worn quite small, and finally are cut quite through, when the rock topples over and the process continues. This is no doubt the way in which the so-called "rocking" or "logan" stones have got into their present condition, although, till this action of wind-driven sand was noticed, people used to fancy that they had either been placed in their present condition by man, or had been worn away by the sea. The sea indeed does, in the same way, wear away the bases of rocky outliers, the sand in this case being driven against their bases by the water instead of the air.

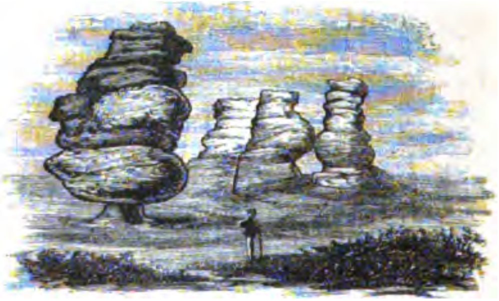

FIG. 40.—Brimham rocks overlooking the Nidd valley (gritstone).

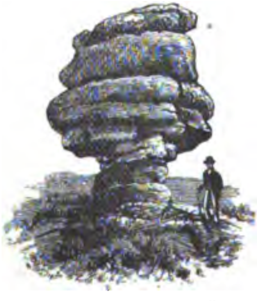

FIG. 41.—The "Cheeswring," near Liskeard, Cornwall (granite).

Although frequently, as in the cases mentioned, the soil is derived directly from the waste of the underlying rock, yet often this is not so, as in the case of blown sand, glacial and river deposits, rain wash, etc. In this case the original surface may be more or less deeply buried under the more recent deposit, and the soil derives its character from the latter. Soils therefore differ very greatly in character, both in texture and mineral composition; and as the soil is, as it were, the stock-in-trade or raw material of the farmer, which he wishes to convert into saleable produce, some acquaintance with it ought to be both interesting and profitable to him. As regards texture, a soil ought to be sufficiently loose and porous to allow its surplus water to pass freely downwards, and at the same time not so loose as to be unable to act by capillary attraction on the stores of moisture below. A gravelly or sandy soil would do the former, but might be unable to keep itself moist by capillarity. If the soil is very clayey, the water is unable to get away downwards, and it becomes water-logged. Two naturally fertile soils, therefore, that is, two soils containing all the chemical compounds required by the crops, might be barren; the one because it is too dry, and the other because of being too wet. In order to assist a soil in getting rid of its water of saturation, drainage is resorted to. A saturated soil is bad because, in the first place, the stagnant water, acting on the vegetable matter, causes the production of injurious organic acids; and secondly, because it prevents the entry of the air into the soil. Most soils contain in abundance the compounds which plants require, such as potash, lime, soda, magnesia, silica, phosphoric acid; but these substances are in an insoluble condition, and are only slowly converted into compounds which are capable of dissolving in water, and of being assimilated by the plant. This process is encouraged by the decomposition of the vegetable soil, or "humus," which is mingled with the mineral soil; and, in addition, ammonia and nitric acid are produced, which are essential to plant life. When, as in a state of nature, the vegetation is not removed from the soil, these soluble matters accumulate; but when crops are removed it is necessary, after a time, to introduce manure into the soil to supply the place of some of the matters which have been taken away. If this is not done the soil becomes impoverished, and, for a time, incapable of producing anything, as has happened in some portions of the United States, where the early colonists, year after year, removed crops from the ground without returning anything to it. The humus plays an important part in the soil, physically as well as chemically. It increases the capillarity of the soil, and its power of absorbing moisture from the atmosphere, and also increases its specific heat. A high specific heat prevents rapid changes of temperature in the soil, which would be injurious to plants. Up to a certain point, therefore, its formation should be encouraged by ploughing in farmyard manure or green crops.

In connection with the question of drainage, it should be remembered that when the various compounds are in a soluble condition, and therefore ready for the plant, they are also ready to be washed away with the drainage water, which, in the course of its passage downward through the soil, will have had an excellent opportunity of collecting and carrying them off. Nitrates are especially liable to be lost in this way, as they are the most soluble of all chemical compounds. The plant-food should remain in the water of imbibition of the soil;[1] it will then be drawn upwards by the capillary attraction, and will be taken up by the roots of the plants.

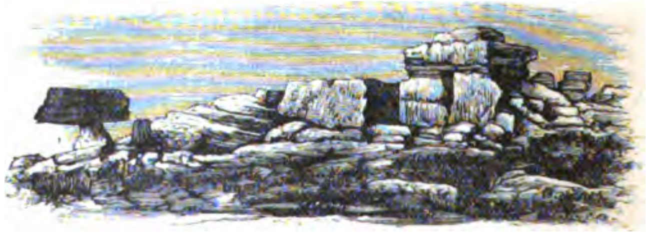

FIG. 42.—Rippon Tor, one of the rocky summits of Dartmoor (granite).

One geographical effect of the presence of a green crop on the soil should be noted. It increases very largely the quantity of evaporation from the surface, and consequently lessens the amounts which either flow off directly or sink into the ground. The immediate surface of the soil will, in hot dry weather, be found to be moister than the surface of a bare soil, because it is protected from the direct rays of the sun; but a few inches down, the bare soil will be much moister than the other.

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[1] Chapter VIII.

The special agricultural character of the soils on the various formations will be described where necessary in connection with those formations.

SUMMARY.—1. Oxygen and carbonic acid, entering the interstices of the rocks, act chemically upon them. The latter, dissolved in water, assists in the solution of limestone and in the disintegration of granite and basalt. Oxygen acts upon the carbonate and silicate of iron, and converts them into oxides. In these and other ways the external surfaces of the rocks become "weathered."

2. Changes of temperature, largely aided by frost, crack and break up the rocks mechanically.

3. This disintegrated rock, augmented by animal and vegetable matter, and mixed up by worms and other burrowing creatures, constitutes the soil, which, though continually being washed away, is as continually renewed.

4. Soil is not always derived from the underlying rock, as it is sometimes foreign matter, such as blown sand, glacial clay, river alluvium, etc.

5. A good agricultural soil should be fairly but not too porous; so that it may (*a*) allow its surplus water to get away, (*b*) draw by capillary action water from the subsoil in dry weather. It should also contain plant-food in a soluble form, and at the same time nothing injurious, together with a sufficient quantity of "humus."

QUESTIONS.

1. How are the various gases contained in the air carried down into the rocks?
2. Explain the effect of carbonic acid on (*a*) limestone, (*b*) felspar.
3. Where do the impurities of clays come from?
4. Give examples of the action of oxygen as a weathering agent.
5. Explain the effect of frost on a sea-cliff.
6. What effect have earthworms on the soil?
7. How have the Brimham rocks been formed? What other theory has been held on the subject? In what respect do the two processes agree?
8. Contrast the condition of a soil near the surface and six inches down in dry weather, when bare and when covered with clover.

CHAPTER VIII.

UNDERGROUND WATER, SPRINGS, AND WATER SUPPLY.

A LARGE proportion of the rain which falls upon the earth soaks downwards through the soil and into the rocks. The relative amount which is disposed of in this manner depends upon the nature of the soil and rocks; loose porous materials, such as sand and chalk, allowing the water to pass freely downwards, and impermeable strata, such as clay, checking it. A little consideration, however, will make it clear that there must be some compensating process at work by which this water is returned to the surface, because, if it were not so, the supply of water would long since have been all swallowed up. Down in the depths of the earth, in the deepest mines, the rocks are found to be saturated with water, and serious difficulty is often experienced in preventing mines from being flooded by the copious supply which issues from the strata which have been penetrated. We know, however, that the earth is intensely hot, and, perhaps, even still molten in its central portions; and the water would probably not penetrate much further inwards after reaching the very hot region, where it would be converted into steam and driven back.

The conditions under which water exists in rocks may be illustrated as follows. Let us suppose a large dry block of chalk to be half immersed in a vessel of water. The part in the water will slowly get as full of water as it can hold; that is to say, it will become "saturated," every crevice and hollow, large and small, will be filled with water. When this state is arrived at, every cubic foot of chalk which is below the water-level will contain eighteen pints of water; *i.e.* it will contain 35 per cent. of its own bulk of "water of saturation." The upper portion will also be found to have become damp, and an examination of its condition will show that it contains ten pints of water per cubic foot; *i.e.* 19 per cent. of its bulk. This water has been soaked up, or imbibed, and is called "water of imbibition," or "quarry water," inasmuch as it represents the ordinary natural moisture of the stone when it is first taken from the quarry. To understand how this water of imbibition has got into the upper part of the block of chalk, take a few small glass tubes of varying size, wet them inside, stand them all up in a glass of water, and observe what happens inside them. It will be seen that the level of the water is higher inside than outside, and that the smaller the tube the higher the water rises inside it. The force which causes this phenomena is called "capillary attraction." It may also be observed if two plates of glass are wetted and brought close together with their lower portions in water, the closer they are the higher the water rises. This is exactly what happens with a sponge or the wick of a lamp. In the latter case, the liquid is removed by burning from the top of the wick, and as fast as it is removed fresh liquid rises up to take its place. The chalk acts in exactly the same way, and if the moisture were removed from the top by evaporation, fresh supplies would rise by capillary attraction from the saturated portion below. As in this particular case the water of imbibition is little more than half the water of saturation in an equal volume of chalk, it follows that in the upper non-saturated portion there must be spaces which have no water in them. These are the larger hollows which are too wide for capillary attraction to fill, and which therefore remain full of air; whereas in the saturated part there is no air at all. The boundary between the saturated and the nonsaturated portions is a plane, which is continuous with the level of the water in which the chalk is immersed. If, now, a hole were to be bored with an auger straight down from the top of the chalk nearly to the bottom, we should find that it would fill with water up to the level at which the chalk is saturated, and no higher. Suppose now that some water is gently poured over the top of the chalk for some time; some will run off and some will soak in. The part into which it soaks will be temporarily saturated; but the water will gradually sink by gravitation till it reaches the saturated portion, where its downward course will be stopped, as there will be no room for it. Near the outside of the block it will easily make its way into the surrounding water; but the water in the centre will not be able to get away so readily, and for some time the surface of saturation, instead of being flat, will be curved, high in the middle and sloping downward on each side. The water in the small well will now stand higher than before; but gradually, as the water presses downwards and outwards, the level will sink to its original position, the plane of saturation gradually becoming less and less curved until it becomes flat as at first. A fresh watering of the block will raise it again; but it always tends to the level which is determined for it by the surrounding water, rising higher when well watered, and sinking towards its limit when left to itself. This experiment illustrates the condition of the dry land under the combined influence of the sea, rain, and evaporation. The saturation-level never sinks much below the level of the sea; below that line the rocks are always saturated. The height to which they are saturated above that line depends on their porosity, the rainfall, and distance from the sea. At the coast the saturation line coincides with the sea-level, from which it rises gently or abruptly according to the nature of the rocks, combined with the rainfall. After a long dry period, the water of imbibition in the upper part of the strata passes off into the air in the form of vapour, or is abstracted by vegetation; but more is drawn up by capillary attraction from the lower portions, so that, however dry the actual surface may be, it is never dry very far down.

The amount of water, either of saturation or of imbibition, which any rock will contain, depends on its composition and texture. The looser the texture, and the more numerous and the larger the cracks, the greater the quantity of water the rock will contain when saturated; but the rock which takes a great deal of water to saturate will not necessarily contain a large quantity of water above the line of saturation, because the cavities between its particles may be too large for capillary attraction to act. Thus a coarse loose sand will contain a large quantity of water of saturation, but it nevertheless makes a very dry soil, because, in the first place, the water can very readily make its way downwards through it, and because, secondly, capillary attraction is weak because of the large size of the spaces between the grains. From what has been said, it is obvious that the amount of water of saturation which any sample of rock or soil can contain depends on the relationship between the hollow spaces and the solid material. The water cannot fill the space which is already occupied by other matter, but the space which the matter does not occupy. Consequently, if we find a sample of sand capable of containing three gallons of water to the cubic foot, which is an extreme case exemplified by the Upper Greensand, according to the observation of Professor Prestwich, it follows that, as a cubic foot is a little over six gallons, the sand itself really fills only half the space, the other half being filled with water. This will serve to show what an enormous supply of water may be stored up in a thick bed of sand below the line of saturation.

The quantity of water which any particular rock may yield, does not depend simply on the quantity it can contain when saturated. The water capable of being drawn off is that which it contains over and above what it is able to hold as water of imbibition. For instance, in the case of the before-mentioned chalk, which contains eighteen pints per cubic foot when saturated, and ten pints of water of imbibition, the amount of water which it would yield per cubic foot would be eight pints, the difference between eighteen and ten.

For practical purposes of water-supply another important factor is the readiness with which any given rock will give off this surplus water. There may be plenty, but the rock may part with it very slowly. Loose sand or a well-jointed and cracked sandstone will part with its water with the greatest ease; but if any clayey material is present the case is very different, partly on account of the strong affinity clay possesses for moisture, and partly through the crevices getting choked with it. Chalk, again, has a very large capacity for water, but a solid lump of chalk, when once saturated, is not at all ready to surrender the water again, as may be seen by trying to drain the water from it. In a well sunk in the chalk the water issues chiefly, not from the chalk itself, but from the cracks and joints. For this reason, it is usual, where a large supply is needed, to drive headings through the chalk in various directions from the bottom of the well in order to tap as many of these fissures as possible.

As illustrations of the foregoing principles a few cases may be cited. A simple and common case is that of a hill with a sandy top resting horizontally on a clay base. In wet weather the sand becomes saturated, but the water cannot penetrate the clay. The water, therefore, presses downwards and outwards, and escapes all round the hill at the line of junction.

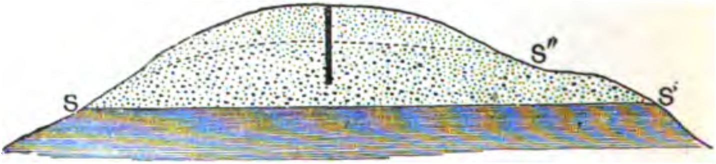


FIG. 43.—A sandy hill resting on clay. s, s′, springs. The dotted line s s″ may represent the level of saturation at any particular time. A well must be sunk below this level in order to obtain water.

This is the most simple and frequent cause of springs. If the strata are not horizontal, but inclined, the springs will be most abundant and continuous on the lower side, but wherever the saturation-line in the sand is above the level of the clay, water will flow out. Along the North Downs the permeable chalk strata repose on the gault clay, with the result that springs issue at numerous points along the line of junction. The character of the water to be obtained from such springs as the above, or from wells sunk into the strata, will depend on the opportunities the water has had of acquiring and parting with impurities during its passage. It acquires impurities in passing through the surface soil, and, if it has been well supplied with various manures, or in parts saturated with materials from drains and cesspools, a great deal of deleterious matter will be carried down. On the other hand, it is greatly improved by its passage through the sand or chalk, partly by the mechanical filtering it undergoes, but more particularly by prolonged contact with the oxygen of the air which exists in the rock, and which, by uniting with injurious organic compounds, oxidizes and renders them harmless. Whether it will be pure or not will depend on the quantity of organic impurity originally present, the time it has spent on its underground travels, and the opportunity it has had of getting purified. For this reason water from shallow wells is generally regarded as unsafe, especially in towns, while deep-seated waters are for the most part quite free from injurious organic taint, not because they never contained any, but because it has all been got rid of.

We may now consider cases of water-supply under slightly more complex conditions, and, as an actual case is better than an imaginary one, we will use as an illustration that presented by the northern slope of the North Downs, in the neighbourhood of Maidstone and Chatham. The strata consist of the chalk formation some 600 feet thick, resting on a bed of impermeable clay about 200 feet thick, below which is a series of sandstones and sands, called the Lower Greensand, which rest on the Weald clay, as shown in the diagram. On the steep southern slope, or "escarpment" of the North Downs, we have the gault at the bottom and the chalk above, both the beds sloping towards the north, with a dip which,

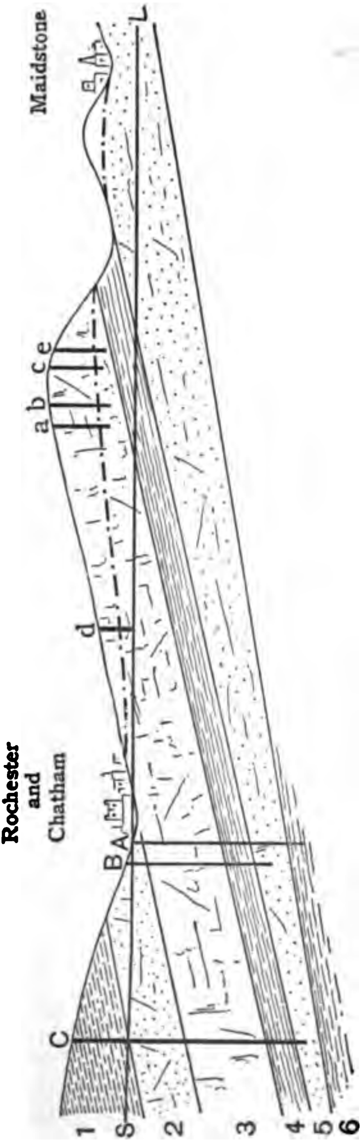


Fig. 44.—Section in the north of Kent. 1, London Clay. 2, Sands. 3, Chalk. 4, Gault. 5, Lower Greensand. 6 Oxford Clay. S L, sea level. The dotted line is the line of saturation. A, B, C, artesian wells sunk into, and in one case through, the Lower Greensand. *a*, *b*, *c*, *d*, *e*, wells in the chalk.

in four miles, carries the top of the gault from 200 feet above the sea-level to 700 feet below it. Consequently the water which sinks into the chalk is checked by the sloping top of the gault, and begins to move slowly northward. The data which fix the lowest level to which the line of saturation is likely to fall are the outcrop of the gault and the sea-level, it is consequently a line 200 feet above the sea in the south, sloping to the sea-level at Chatham, and wells must be sunk down into the chalk below this line to make sure of a constant supply of water. On the top of the downs there is a well 360 feet deep (*e*), while as we go further north and decrease our elevation the depth of the wells is less and less. The wells supplying water for Rochester, Chatham, and Strood (*d* in diagram), are sunk from an elevation of about 120 feet, and the level of the water in the wells is about 100 feet from the top, which gives an elevation for the line of saturation at those points of about 20 feet. The chalk plateau lying at the back of the North Downs at an elevation of from 300 to 500 feet is very badly off for water, the wells being very deep, and consequently expensive to make, and comparatively few in number (*a*, *b*, *c*, in diagram).

The water obtained in this manner from deep wells in the chalk is very free from organic impurity; but is very hard, containing about sixteen grains of dissolved chalk in every gallon. This is a serious objection to the water on account of the strong deposit which is left by hot water in kettles, boilers, hot-water pipes, etc., and also because of the waste of soap and the inconvenience when the water is used for washing. Many of the towns which obtain their water from the chalk consequently put themselves to the expense of "softening" it, among them Canterbury, Wellingborough, and Southampton. The process employed is that suggested by Dr. Clark fifty years ago, and is briefly as follows. Water acquires the power of holding carbonate of lime in solution whenever it contains carbonic acid, which appears to unite with the insoluble carbonate of lime, and convert it into the soluble bicarbonate. The carbonic acid can, however, be easily detached again, when the carbonate is reformed. This happens when water is boiled, the carbonic acid being expelled from the water by the heat. Dr. Clark, however, was the first to point out that if lime is added in just sufficient quantity the bicarbonate may be converted into the carbonate, and there being no free carbonic acid now present in the water, it remains undissolved and may be removed either by precipitation or filtration. In this way more than three parts of the dissolved matter are removed, and the water rendered quite sufficiently soft. The process is very simple and inexpensive, not amounting to more than one farthing per 1000 gallons for working expenses.

There is still another form of well which may be illustrated by examples in the same neighbourhood. The Lower Greensand beds are very permeable, and capable of containing a large quantity of water, and they are shut up between two layers of impermeable clay. Moreover, they slope downwards to the north, getting very much thinner as they go, and they expose a large surface to the weather in the country south of the escarpment round about Maidstone. Much of the rain which falls there sinks downwards, till checked by the Weald clay, and then travels northward down the slope, so that the greater portion of the whole mass of the Greensand strata is saturated with water, with the saturation-level some height above the sea. Consequently, when at Chatham or Rochester borings are carried down through the chalk and gault into the Greensand beds, the water rises up and flows freely from the mouth of the tube (A, B, Fig. 44). At another locality further north, on higher ground, the same thing happens, the height to which the water tends to rise in the tube being the same as the height of the line of saturation in the catchment area to the south. This water has not travelled through the chalk, and is consequently "soft." Wells and springs in which the water rises in this manner from a depth are called "Artesian," because they were first made in Artois. The advantage of them is that the water rises without any further trouble.

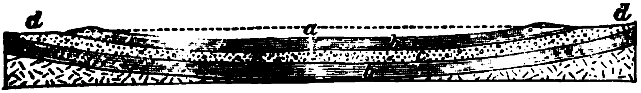


FIG. 45.—An artesian well (*a*) bored down into a permeable stratum (*c*). The rain finds entrance into the stratum *c* at *d*, *d*. *b*, *b* are impermeable beds.

They are only possible where the geological conditions are favourable, and it is curious that this is the case both in London and Paris.

Shallow surface wells, deep wells in which the water is raised mechanically, and artesian wells are the most common sources of our domestic water-supply, though the first kind, being very liable to contamination, should be used as little as possible. Many towns, to a large extent London among them, draw their supply from the upper portions of the rivers on which they stand. Such water is, of course, much more liable to contain injurious organic matter, even if it is filtered before being used. Small local supplies in the country are often obtained from natural springs, which issue from the surface either in the manner already described, or from fissures and faults in the rocks. Some of these springs, rising from a depth, are quite wholesome, though they generally contain more or less dissolved mineral matter. If they contain sufficient to give them a special and recognizable character, they are called *mineral springs;* and if of use medicinally, they are called *medicinal springs.* By far the most abundant of these dissolved materials is carbonate of lime, the deposition of which, as large masses of travertine, has been already described. Salts of magnesia, potash, and soda are also

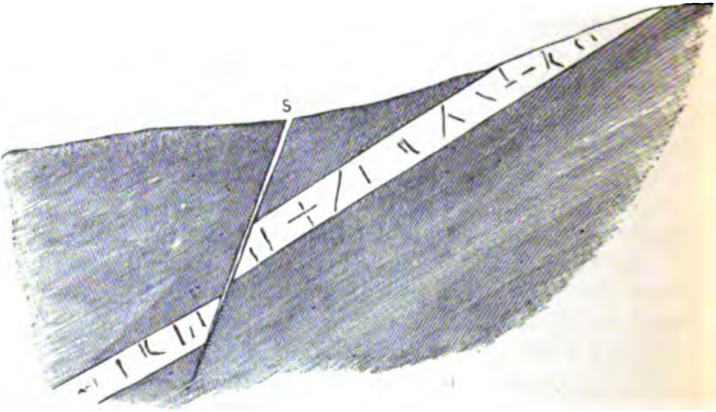


FIG. 46.—A fault spring at S.

common in such springs. When the water comes up hot or warm from a great depth, it is called a *thermal spring*, and it is then still more likely to bring up dissolved material, especially silica. Salts of iron are characteristic of the *chalybeate* springs. Gases also, such as carbonic acid and sulphuretted hydrogen, are not uncommon. There is a great variety of springs at Harrogate—some chalybeate, some saline, and some sulphuretted. Vichy water contains bicarbonate of soda; Epsom, sulphate of soda; Seidlitz, sulphates of magnesia and soda; while those of Wiesbaden contain common salt. Waters containing gas only are nevertheless popularly included under the title of "mineral waters," though apparently it is not legal to sell them as such.

As nearly all the water which comes out in springs finds its way by means of the rivers down to the sea, it will be readily understood that the sea is really a very complex mixture of most of the mineral substances which can be dissolved in water, although it does not follow that everything remains permanently in solution in the sea which the rivers bring into it. If it did, there would be very much more carbonate of lime in solution in sea-water than anything else; whereas, as a matter of fact, there is very little, while there is a large quantity of common salt. The reason of this is, that marine animals are continually appropriating to themselves the carbonate of lime, which gets converted into shell and bone, while there is no particular demand for the salt, which therefore remains in solution and accumulates. The silica, also, is removed from the sea by various organisms, such as diatoms and certain sponges. The following table represents the composition of an average sample of sea-water:–

Pure water	96·470	Calcium carbonate	0·003
Common salt	2·700	Magnesium bromide	0·002
Magnesium chloride	0·360	Silica, iodides, etc.	0·025
Potassium chloride	0·070		
Magnesium sulphate	0·230		100·000
Calcium sulphate	0·140		

Very little dissolved matter is intercepted by a lake when a river flows through it, the lake being merely, as it were, an expansion of the river; and, except that it is clearer, the water which flows out at the lower end is very much the same in character as that which flows in at the upper. It is otherwise, however, when a river flows into a lake and does not flow out again. When this happens it is generally because the water evaporates from the surface of the lake as fast as it is brought in by the river, so that the lake never rises high enough to run over. In this case it is pure water which is evaporated from the lake, while impure water flows in. Consequently, the dissolved impurities accumulate in the lake instead of in the sea. The lake, therefore, is to the river what the sea is to most rivers, and is always more or less salt. To suggest this similarity, such lakes are generally called *seas*, not *lakes*. Some such lakes, as, for instance, the Sea of Aral and the Dead Sea, are much salter than the sea itself.

Organic matter is only found in surface waters, or in the water from shallow springs and wells. This, fortunately, does not accumulate in lakes and seas like inorganic matter. Not only does it disappear from water which has percolated through any thickness of rock, but impure water of this kind generally becomes much purer after it has been flowing along in a brook or river exposed to the air, partly by the oxidation of the material, and partly by its becoming the food of various small creatures which live in the water. It is found that in rivers and estuaries, where the sewage of our large towns is poured, there exist multitudes of minute crustaceous animals, which rapidly reduce the various organic impurities in the water to a harmless state by devouring them.

Before closing this chapter, there are one or two phenomena connected with springs which should be mentioned. The first is the *intermittent* character of some springs. These are in the habit of flowing freely for a time, then resting, then starting again. Several ingenious theories have been invented to explain them, which are no doubt true of special cases; but the cause of most of them is probably that which is illustrated in the following diagram (Fig. 47), which is quite independent of the formation of the accidental siphons communicating with cavities full of water, which have been largely figured in text-books.

Another curious case is that of a spring of fresh water bubbling up at the bottom of the sea. When a bed of permeable rock runs down under the sea, it still retains its water of saturation, and does not take up the salt water to any large extent. A little consideration will make this clear. The dotted line in Fig. 48 represents the line of saturation, the tendency of which is to sink until it becomes level with the sea, forcing the water of saturation from the rock outwards towards the sea. Suppose a tube to be inserted, as in the diagram, the portion A C being full of salt water, and C B full of fresh water. If the water-level at B is much higher up than that at A, there will be a greater pressure from B towards C than from A towards C; consequently the water which is at

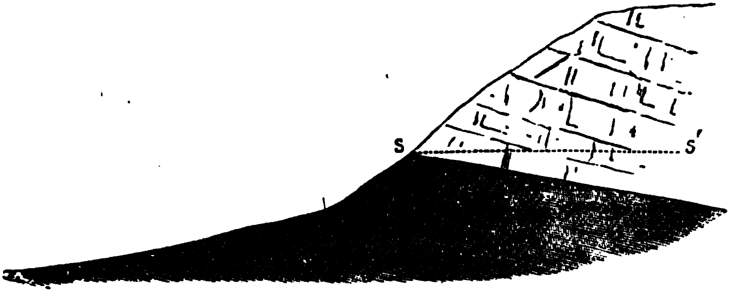


FIG. 47.—An intermittent spring. Chalk resting on clay, and the strata dipping into the hill. As long as the level of saturation is above the line S S′ water will flow out at S; when below it, the flow will stop.

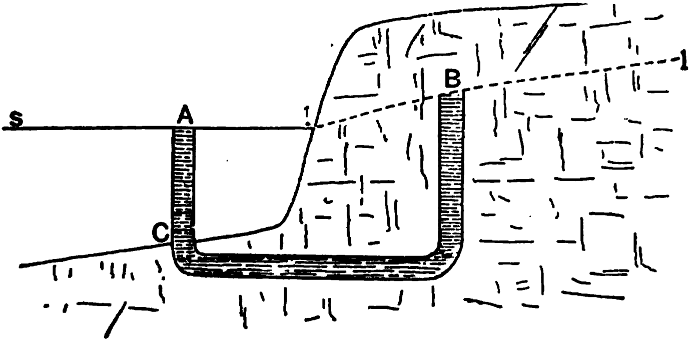


FIG. 48.—To illustrate a submarine fresh-water spring.

C will move in the direction of the greater pressure, that is outwards, and this will not be affected if the portion A C of the pipe is removed. This will apply to all the crevices in the rock which are full of water, and will explain why the sea does not soak into the rock, why and under what condition springs may exist at the sea-bottom, and why wells near the coast or on low flat coral and other islands may give a supply of fresh water though they are sunk below the sea-level.

In connection with such wells there is another curious phenomenon. Though perfectly fresh, the water-level in them rises and falls with the tide. The appended diagram will make the reason of this quite clear. As the line of saturation cannot fall below the level of the sea, *l l* will represent its position at high water. As the tide falls, the water near the cliff will be drained off, and the level will be lowered, but less and less the further we go inland, till at a certain distance there is no change at all.

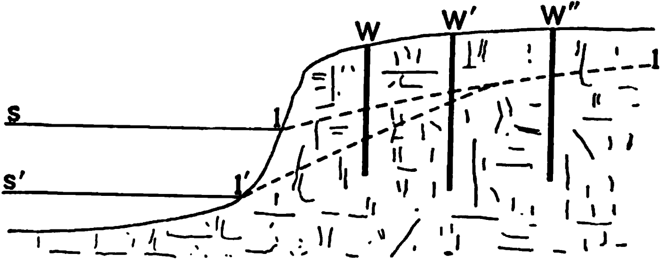


FIG. 49.—*s l*, high water mark; *s′ l′*, low water.

At low water, therefore, the line of saturation will be *l′ l*. A well sunk at W will, it is clear, alter its level considerably as the tide rises and falls. One at W′ will alter slightly, and another at W″ not at all. It is clear that the level in the first two is higher at high water, not because the sea-water soaks in, but because it dams back the fresh water and prevents it escaping so freely. If, however, large quantities of water were to be pumped from the well W, the level of saturation might be lowered sufficiently to allow the sea-water to soak in, and then, of course, the well-water would be salt.

It is unnecessary to enlarge on the importance of all questions concerning water-supply in a country so thickly populated as England. The two great questions in any locality are (1) the quantity of available water, and (2) its wholesomeness, or the contrary. Minor questions are its accessibility and its special characters. A committee of the British Association has been in existence for some years with the object of collecting and disseminating useful information on this topic, and to this end they have published a series of questions to be answered, of which the following are a summary :—

1. Specify the exact position of the well.
2. When was it sunk?
3. How far is it to the bottom?
4. How far is it to the surface of the water—
    (*a*) in winter?
    (*b*) in summer?
    (*c*) when exceptionally high?
    (*d*) when exceptionally low?
    (*e*) Does the level seem, on the whole, to get higher, lower, or to remain stationary?
5. Is there anything noticeable in the character of the water?
6. Through what materials is the well sunk? Give as full details as possible.
7. Does the surface water get into it?
8. How long does it take before wet weather causes the level to rise?
9. If the water is ever pumped in large quantities, how much per day can be got from it?
10. Any further remarks.

If these questions could be answered for every well in the country, some very useful generalizations would result, with perhaps the publication of a map, on which the average depth of the saturation level, with its range of fluctuation, would be indicated for all parts of the country. Persons wishing to get some preliminary information respecting their underground water would not then be tempted to employ such a relic of mediæval superstition and ignorance as the "divining rod."

SUMMARY.—1. A certain portion of the rainfall sinks into the strata, and descends till stopped or diverted by impermeable strata or by the subterranean heat.

2. Below a certain level the rocks of the earth's crust are "saturated." Above that level they are, for the most part, wet with "water of imbibition." To obtain water in a well, it must be sunk into the former region, when the quickness with which it will fill will depend on the relative amounts of water of saturation and imbibition respectively, and upon the nature of the rock.

3. Consideration of special cases of water-supply—
   (*a*) from surface waters in springs and shallow wells.
   (*b*) from deep wells, by pumping.
   (*c*) from artesian wells.

4. Impurities present give special characters to waters, mineral, medicinal, chalybeate. Thermal springs.

5. The principles laid down easily enable us to understand intermittent springs, submarine springs, water-level in wells rising and falling with the tide while the water remains quite fresh.

6. It is very desirable to accumulate full and complete information as to the underground water-supply of all thickly peopled countries, both for health and for economy.

QUESTIONS.

1. Upon what conditions does the amount of water taken up as (*a*) water of saturation, (*b*) water of imbibition, depend? Give instances.
2. Explain why the level of saturation is generally above the sea-level, and always tending towards it.
3. Upon what does the supply of water to a deep well depend?
4. How long would the water from a cubic mile of saturated chalk last ten thousand people, allowing each person ten gallons per day?
5. How does water in the course of its wanderings through the strata become (*a*) contaminated, (*b*) purified?
6. How is hard water softened by Clark's process?
7. Mention a few common "mineral waters," with their characters.
8. How do you account for the composition of sea-water?
9. Explain an *intermittent spring*, and an *artesian well*, with diagrams.

CHAPTER IX.

GEOLOGICAL ACTION OF RIVERS.

RIVERS are the vehicles by which the rain which has fallen on the land is returned to the sea. With the water is carried all the material which it has dissolved out of the soil and rocks, and a large quantity of suspended matter washed from the

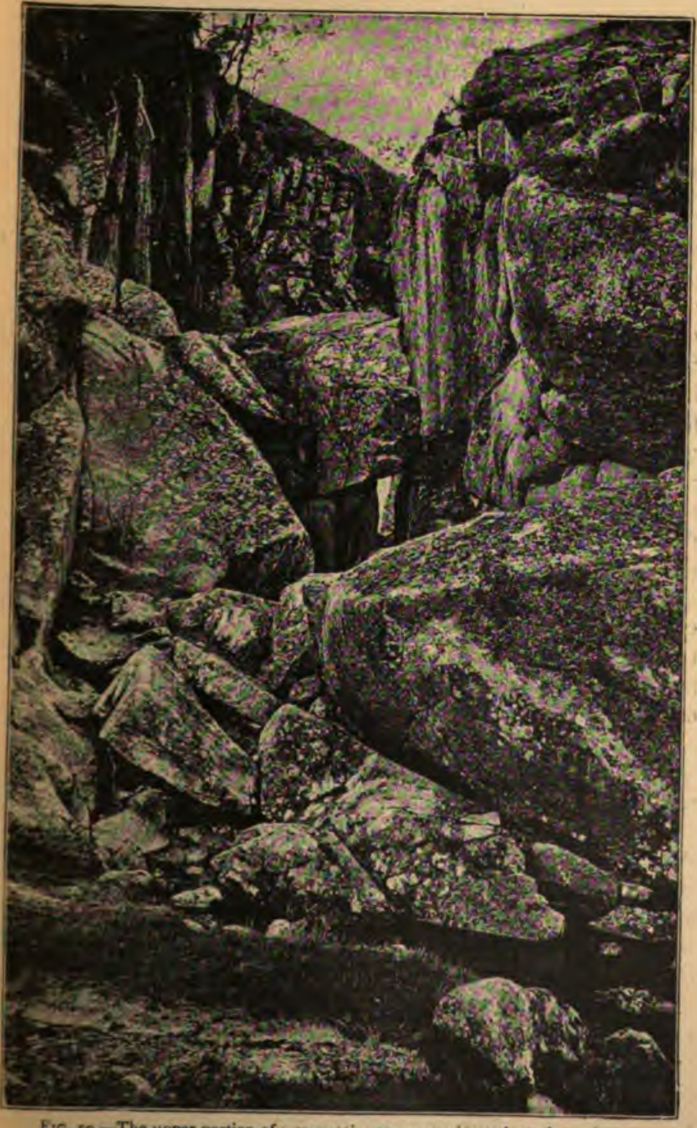


FIG. 50.—The upper portion of a mountain stream cutting a deep channel.
[The Burn of Yat, looking up Loch Kinnord. Wilson.]

earth's surface. The direction which rivers take in their course to the sea is often very tortuous, and not always easy to account for. As a rule, rivers flowing slowly over a flat alluvial plain wind about very much, as if they were indifferent which direction they took; but, on the other hand, there are winding rivers, like the Moselle, which flow in a deep rocky channel. Some rivers, like the Darent and Medway in Kent, flow through valleys which they have evidently cut through a ridge of high ground at right angles to their own direction, although it is obvious that, if the valley were again filled up, it would be quite impossible for the river, as it exists at present, to re-excavate it. To understand how the rivers came to flow in their present channels it is necessary to try and restore, in imagination, the original surface of the earth when the river first came into existence. At that time the river took the most easy course to the sea, following the same laws as direct a runnel of water streaming down a sloping road after a shower; and from then till now the river has been slowly deepening its channel, and carrying down it, not only the excavated material, but also all the mud and other matters brought into it by all its tributary streams, and collected from every part of the river basin. The water which flows down the river, therefore, did not begin its denuding action when it first reached the river, but when it first fell as rain on the earth's surface. Every drop of water which flows off the ground carries with it some small portion of the loose material which has been already prepared for removal by the weathering agents described in the preceding chapter. It does not follow that every particle which is taken up is carried without any further stoppage down to the sea; but it should be remembered that every movement which it makes is in that direction —*i.e.* always downhill. Most surface streams are muddy with such particles, and many rivers which flow out of mountainous districts, especially if they originate in melting glaciers, are extremely muddy, the amount of mud occasionally rising to one in every hundred of water, though one part in five hundred will make a muddy stream. The amount of solid, suspended matter carried in this way by rivers down to the sea is a very interesting point, and has received much attention from many observers. The Mississippi has been carefully examined in this respect, and, as it is a typical river, collecting its waters from a great variety of regions, it probably represents roughly the average amount of matter removed from any area of the same size on any other part of the earth. The proportion is one in every fifteen hundred of water—an amount sufficient to lower the surface of the basin one six-thousandth part of a foot per year, or one foot in six thousand years. Taking one part of the surface of the dry land with another, it has been calculated that the average height above the sea is about two thousand feet. At the above rate, the whole of this dry land would be brought down to the sea-level in 6000 × 2000 = 12,000,000 years. It should, however, be remembered that the denudation is not equal all over a river basin, as it depends in each place on the nature of the material to be removed, the rainfall, elevation, slope, and various other conditions.

A river, then, is the recipient and carrier seawards of material received from all parts of its basin, as well as the excavator of its own special channel. The way in which it does this latter work is by cutting vertically downwards into the earth's crust, at a rate depending on the velocity of the river and the character of the material to be cut into. The velocity of the river depends practically almost entirely on the slope; though, of course, with any given slope, the smaller and straighter the channel the greater the rate of flow. A fall of one foot in a mile is quite sufficient to carry a river steadily onward; one foot in a thousand feet will make a fairly rapid river; one in two hundred, a torrent. Rivers with falls greater than this become rapids. The transporting power of a rapid stream is remarkable, the largest boulders being moved with apparent ease. One reason of this is that stones, like all other solids, lose, when in water, an amount equal to the weight of the water they displace; so that a stone weighing, say, 250 pounds would really only weigh about 150 pounds in water. Another reason is that stones in rapid motion in the stream are dashed with great force on others at rest, and so set them in motion. As they move they all knock and rub against each other and against the banks and bottom of the stream. In this way the corners are knocked off, and the stones become smoother and at the same time smaller, the bottom and sides of the channel are cut out, and a quantity of sand and other fragmentary material formed and carried away by the rushing water. Thus it will be found, if a mountain stream is followed downwards, that the stones in its channel, though obviously derived largely from the upper regions, are smoother and smaller than those near the source. An interesting and striking illustration of the way in which a few small stones will wear away a rocky surface by continually grinding over it may be seen in the "pot-holes" so common in the beds of mountain streams. These are circular holes, often two or three feet deep, cut vertically downward in the rock by a few pebbles which are kept continually whirling round at the bottom of the hole by the rushing stream. As the river flows on, the slope gets much less, until, as it nears the sea, the channel seems perfectly level, and the tidal portion of the river is reached. Here the eroding power of the river has ceased, and, as time goes on, the tendency is for this tidal portion to extend further and further up the river. The limit downwards to river erosion is therefore low-water mark. If we find a case, as we often do, of a river whose bed seems to have been cut down below that level, we must assume that either the land once stood higher, or that at some former time there was, for some geographical reason, a greater difference than now between high and low water, the high water rising to a higher level than now, and the low-water mark sinking lower. This would allow the river at low water to scour out its channel to the same level.

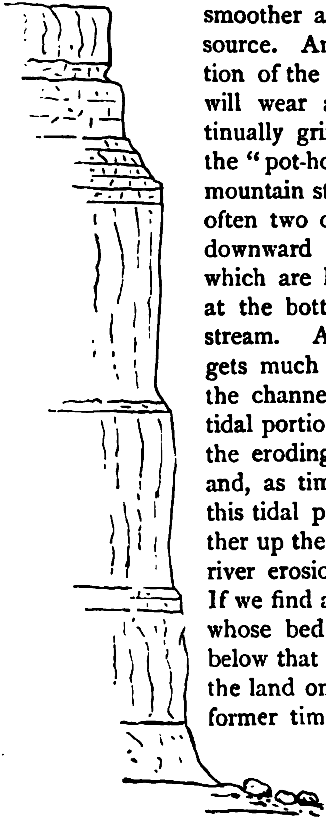


FIG. 51.—Geological section of one of the sides of the ravine, or *cañon*, of the Colorado.

Although a river as it flows along cuts away its banks a little, yet the main action is directed downwards, the gently shelving sides of the valley being due to rain. In order to eliminate this latter action, so that we may see what running

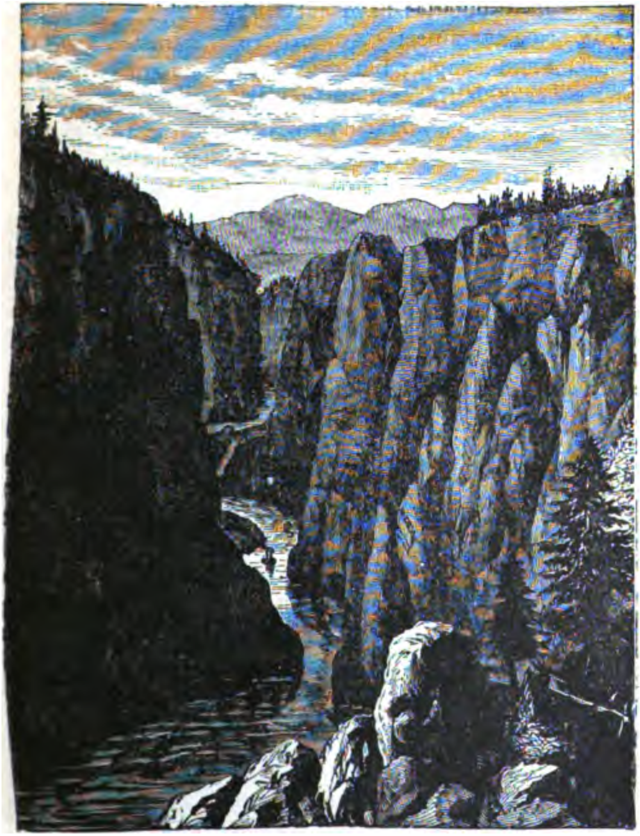


FIG. 52.—A cañon.

water alone is capable of doing, we must study some river flowing with a fairly rapid and originally elevated stream through a district nearly or quite rainless. The most striking case of the kind is that of the Colorado, which flows from the

Rocky Mountains across the arid and lofty plateau of Utah and Arizona, down into the gulf of California. The plateau is composed of an immense number of nearly horizontal strata of limestone and sandstone, piled one on the other; and the river and its tributaries have cut ravines with perpendicular sides, in some cases nearly a mile deep. Here we have river action pure and simple; but when the strata are soft and the rains are heavy or frequent we get a broad open valley with very gently shelving sides: and between these two extremes every variety of slope, depending on the hardness of the rock and the rainfall. In the lower part of a river's course the valley is generally much wider and the slopes consequently more gentle. The reason of this is twofold. The general surface of the land slopes down towards the sea, so that there is not such a great thickness for the river to cut through; and in this part of the course of the river the downward erosion has often long since ceased, while the erosion of the sides by the rain still goes on. The erosive action of the river, therefore, is not only more intense in the upper part of its course, but is continued for a longer period. The gathering ground of a river in a hilly or mountainous region generally forms a semicircular recess at the head of its valley, down the sides of which numerous streams descend and unite their forces at the bottom. This is where the eroding action is greatest. These streams gradually but finally cut their way back, right through the hill, and draw through the gap the drainage of the country on the other side, and so secure a larger basin for their stream. In this way a river sometimes flows through a gorge which it has not cut itself, but which has been cut for it by a stream on the other side eating its way backward.

The formation of a ravine is often assisted by the action of a waterfall. A waterfall is originally caused by a soft stratum of rock underlying a harder one and getting worn away downwards and backwards till the edge of the harder layer projects over it. The mechanical wearing action of the river is greatest where it rushes over the rocky ledge, and consequently this ledge is continually being cut back further and further up the river, the softer stratum below keeping pace with it. Niagara is a good instance of this. The gorge below the falls, through which the river rushes in a tumultuous current, called the "Whirlpool Rapids," has no doubt been formed in this way, and the waterfall is thus receding further and further from Lake Ontario, and approaching Lake Erie, at the rate of, it is said, some four or five feet a year. If this rate has been the same during the whole process, as the gorge is seven miles long, it has taken ten thousand years to cut it. No doubt other gorges have been cut in this manner, though the waterfalls have now quite disappeared.

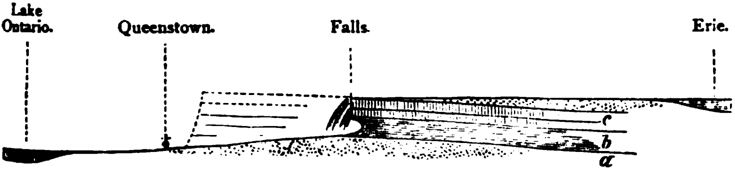


FIG. 53.—Section showing the rocks at the Falls of Niagara. *a*, sandstone; *b*, shale; *c*, beds of limestone.

The distance which a river will carry its cargo of eroded material depends on its velocity and the character of the material. Deposition begins long before erosion has ceased. The larger boulders and masses of rock are left behind in the upper torrential portion of the river, and are only perhaps moved in time of flood; smaller stones and pebbles are carried a little further: but far below this point the stream continues to excavate its channel more deeply and to wear away its banks and bear off the waste. In a winding river especially, erosion and deposition may be seen going on in the same part of its course, the stream undercutting its bank on the convex side of the bend and throwing down material on the side directly opposite (Fig. 54). This peculiar action of a meandering river produces important results, as it brings about a perpetual shifting of the course of the river, partly as its direct consequence, and partly by the river, in time of flood, making and afterwards retaining short cuts between two adjacent bends. On examining a large-scale map of the lower course of the Mississippi numerous horseshoe-shaped lakes and ponds may be observed, marking the position of the old channel (Fig. 55). In this way in course of time a river wanders to and fro over its plain, cutting up and removing at one time material which it has formerly deposited. At the same time, when in a state of flood, it overflows its channels and swamps its alluvial plain with muddy water. The speed of the river being in this way retarded, much of the mud is let fall, and the alluvial deposit left a little thicker than it was before. In this way it gets thicker and thicker, and its surface higher and higher above the ordinary level of the river, until at last it becomes too high to be flooded except upon extraordinary occasions. If now any change occurs which accelerates the speed of the river, the stream gradually deepens its channel again, and at the same time clears off the greater portion of its own alluvium and carries it down to a lower part of its course. Small portions of the old alluvium are here and there left on the sides of the valley to tell us that the river once flowed at that height, and in the course of time another alluvial deposit perhaps accumulates at a lower level in

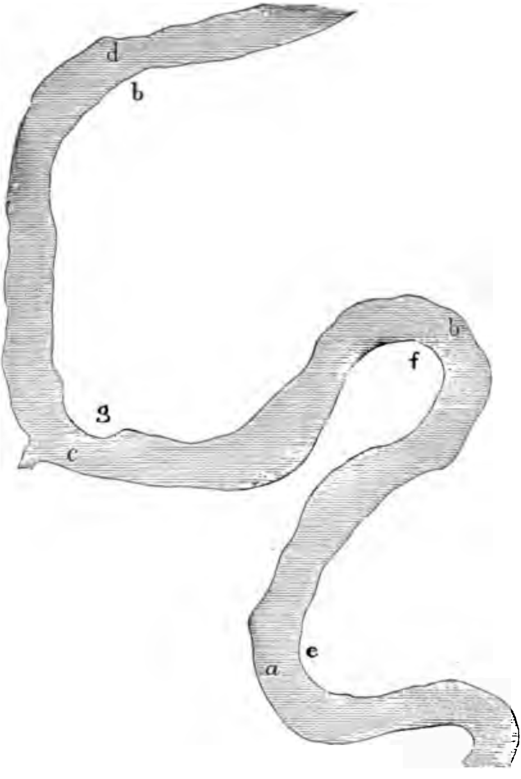


FIG. 54.—A portion of the course of the River Medway near Rochester. Banks eroded at *a*, *b*, *c*, *d*; silt deposited at *e*, *f*, *g*, *h*.

the same part of the valley, which in its turn is again removed and succeeded by a third still lower down. This is how river "terraces" (Fig. 56) are formed, and they serve as land-marks in the history of the erosion of the valley. The material of which they are formed is irregularly stratified, and shows every sign of having been thrown down by running water. These deposits often contain prehistoric remains both of man and animals, such as flint implements and mammoth tusks. It is, of course, obvious that, in the case of two or more river terraces of this kind in the same part of a valley, the highest is the oldest and the lowest the most recent, though it would be unsafe to attempt

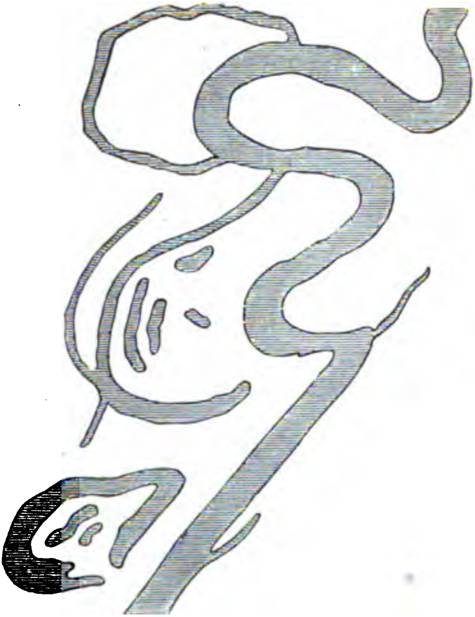


Fig. 55.—Present, and old deserted channels of the Mississippi.

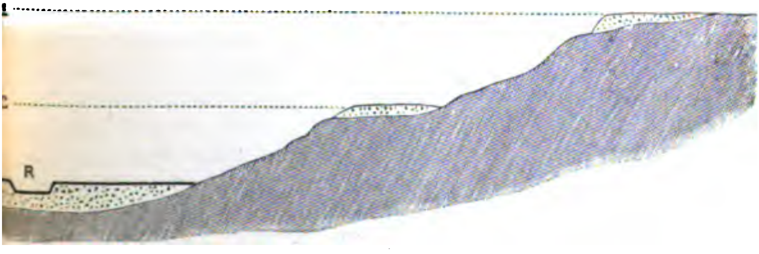


Fig. 56.—1, 2, levels at which the river was flowing when the upper and second terraces were formed respectively. R, the present position of the river. The dotted portions represent material brought by the river.

to fix the relative ages of such deposits if they were far apart.

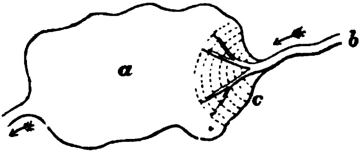


Fig. 57.—Stream (*b*) running into a lake (*a*) and forming a delta, and finally an alluvial plain (*c*).

Lakes have a very important influence on rivers which pass through them. Without at present pausing to consider their origin, it often happens that hollow places present themselves in the course of a river as it proceeds on its course. A river just commencing its career would be stopped by such a state of things, and would at once begin to accumulate its waters and form a lake, until it rose above the level of the lowest part of the rim, when it would flow over and proceed on its course. In the lake, especially if it were at all deep, the water would be almost stationary, and the mud and sediment of all kinds which was being carried along by the river would be dropped when it entered the lake, and would in time form a thick deposit at its upper end, which would continually increase and tend to fill up the lake. In the mean time the water pouring over the obstructing rim would gradually cut it downwards, and so lower the level of the water in the lake, so that from the very moment of its formation two processes have been going on tending to obliterate it: one, at the upper end, filling it up with sand and mud; and the other, at the lower end, drawing off the water. In mountainous countries especially this work can be seen in every stage. The lakes of former times are now indicated by flat alluvial grass-covered plains with a river flowing down their centres, and often passing into a rocky ravine at their lower extremities. The existing lakes all show signs of the same process at work. Lake Geneva, for example, where the Rhone enters it, is shallow and muddy, and a flat alluvial deposit extends some distance up the valley. The contrast between the river above the lake and the river below is also very marked. Above, it is white with fine glacial mud; below, beautifully clear. These lake deposits are often composed of very fine clayey mud, in which are embedded fresh-water shells from the lake, in company with leaves and other vegetable matter washed down by the river. Such deposits are common among geological strata of nearly all ages, and serve to illustrate the uniformity of these processes throughout all time.

Finally, however, most of the fine alluvial matter reaches the sea, but the manner of its disposal there will depend upon circumstances. When the tidal portion of a river is reached, the stream with its burden of suspended material is twice a day dammed back by the tide, and it at once begins to let fall a great deal of its load. This is why estuaries and tidal rivers are so muddy. As the salt water withdraws with the ebb tide, the fresh water follows it, and both salt and fresh water bear a considerable quantity of mud out to the mouth of the river. The coarser and heavier material sinks down near the river-mouth, forming *bars* and obstructions to navigation; while the finer is carried along for great distances by the ebb tide, and far-spreading mud-banks formed. At the mouth of the Thames, for example, while a considerable quantity of mud is left behind in the estuary, a still larger amount is drawn off by the ebb tide and deposited along the Essex coast. The scouring action of the tide generally keeps the central portion of the river channel more or less clear of deposit; but where rivers empty themselves into a tideless sea, like the Mediterranean, the result is practically the same as when they flow into a lake. The river deposits its sediment as soon as it reaches the sea, and tends to choke up its mouth, forming in time an alluvial marshy district, which continually encroaches on the sea, and through which the river, often by a multiplicity of channels, finds its way as it can. Such deposits are called "deltas," from the name originally given to that of the Nile. In some cases, as, for example, the Mississippi and the Po, the river gradually tends to fill up its own channel, and so slowly raises itself to a higher level, and the more it is artificially banked up the more it does so. In this way the Po flows many feet above the alluvial plain which surrounds it. The amount of alluvial matter in some deltas is enormous. The Ganges delta has an area of forty thousand square miles, and at Calcutta there is a thickness of about five hundred feet of river deposit. The Mississippi delta is larger still, and a boring at New Orleans 630 feet deep did not reach the bottom of it. If the rivers with such deltas have been bringing down sediment continually at their present rate, it is obvious that, by dividing the amount of material in the delta by the amount which the river is calculated to bring down in a year, we shall get an approximation to the time during which the deltas have been forming. The following are the figures which have been calculated for a few notable rivers: the Nile, 17,000 years; the Ganges, 21,600 years; the Rhone, 6,500 years.

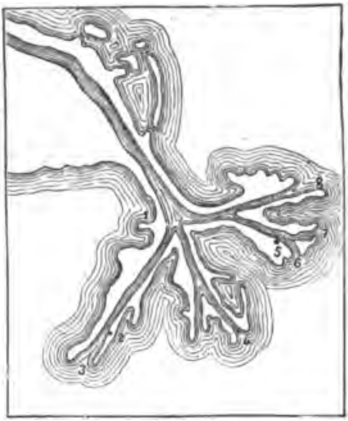


FIG. 58.—Lower portion of delta of Mississippi. 3, 4, 6, 7, and 8, channels.

These delta deposits and their extensions of still finer materials, extending far away at the bottom of the sea, represent the fine-grained sandstones, clayey sandstones, shales, and clays of the future. As they are forming now before our eyes, no doubt many of the hard rocks which constitute the earth's crust have been formed in bygone ages. As the materials of the Ganges delta have been brought down by the river from all parts of its basin, from spots hundreds, even thousands, of miles apart, and from all kinds of rock, so the older rocks have been built up of materials collected in the same way from strata still older. The *London clay* is such a deposit, and appears to be formed of material brought down by some great semi-tropical river, the only proof of whose existence is found in its preserved delta, with its embedded palm fruits, vertebræ of crocodiles, and other fossilized remains, which could only have been brought down from a warm region. The consideration of rivers and their doings, like all other branches of geological study, impresses the mind with the vast antiquity of the earth, and with the constant succession of changes which it has undergone. Nothing is stationary:

mountains and tablelands are being borne away to form deltas; lakes are being converted into alluvial plains; and waterfalls carry with them the seeds of their own destruction.

SUMMARY.—1. The present course of a river can best be accounted for by restoring in imagination the geography of the period when it first began to flow. By so doing, many anomalies, such as rivers flowing through escarpments, can be explained.

2. The water of a river is collected from the whole basin, and has been employed in denuding the whole surface before it joins the main stream. The action of a river is therefore twofold.

3. The channel of a river always tends to low-water level, when, and even before it reaches this, the tide enters and forms a muddy estuary.

4. The chief work of a river consists in (*a*) lowering the general level of its basin; (*b*) cutting its channel downwards, and backwards at its source; (*c*) converting lakes into alluvial flats; (*d*) forming deltas, bars, and mud-banks and sand-banks.

QUESTIONS.

1. Upon what does the character of a river valley depend? Give examples of different kinds of valleys, and account for them.
2. How can an idea be formed (1) of the rate at which a river lowers the surface of its basin, (2) of the time during which the river has been in existence? What chances of error are there in such calculations?
3. Describe the action of a river in carrying coarse material downward, and explain how such a process is facilitated.
4. Where should we find the materials which the river has carried away in suspension and in solution from its basin?
5. Describe river terraces, and explain their bearing on the history of the river.
6. What inference would you draw from the fact that a river channel some miles from its mouth is encumbered by mud forty feet thick?
7. Explain, with a diagram, how waterfalls originate and terminate.

CHAPTER X.

ACTION OF SNOW AND ICE.

WATER plays an important part in nature in each of its three physical conditions—as invisible vapour in the atmosphere; as liquid water in the shape of rain, streams, lakes, and seas; and in its solid form of snow and ice. It assumes the latter state whenever and wherever the temperature falls below 32° Fahr. The atmospheric vapour, condensing into water and solidifying under the unrestricted play of the crystallizing force, assumes, as it floats in, or falls through, the air, a great variety of crystalline forms, which differ much in detail from each other, but which all agree in having a hexagonal skeleton; the simplest consisting of three delicate needles of ice of equal length, crossing each other at a central point at angles of 60°. They may be best seen in the fine dry dusty-looking snow which falls on a calm cold day, as in this state they reach the ground without adhering to and crushing each other, as they do when they form large snowflakes, which are simply masses of these snow crystals. When water freezes there is the same hexagonal tendency; but the crystals are not there so free as in the air, and the result is that they soon form a transparent and apparently homogeneous mass of ice. Even in ice, however, Professor Tyndall has shown that the hexagonal crystals exist, and has made the fact visible by causing some of them to melt when rays of heat are passed through the solid mass.

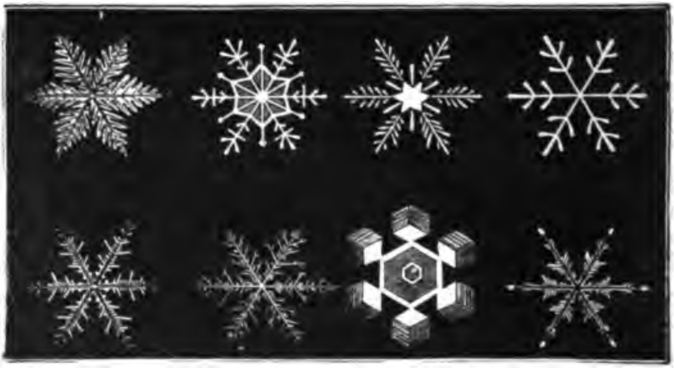


FIG. 59.—Specimens of snow crystals.

Sometimes the atmospheric moisture descends in the form of hail, which looks sometimes as if it were merely frozen raindrops, at other times like half-melted snowflakes formed into little snowballs and then covered over with a coating of ice. This latter kind may have been formed by snow getting half melted by falling through a warmer stratum of air and then getting frozen again.

We are not, however, so much concerned with the special conditions under which snow and hail are formed, and what happens to them as they fall to the earth, as with the conditions in which they exist on the earth and the work they do there. In most places where snow falls, it remains in the place in which it fell till it melts, and then runs away or soaks into the ground very much as a shower of rain would. But there are certain parts where it does not melt, at any rate as fast as it accumulates, and, as a consequence, the surface is always more or less covered with snow. This is the case in the Arctic and Antarctic regions, and on all parts of the world, wherever they are, that rise above the "snow-line." The "snow-line" may be defined as the boundary plane which separates the region above it, where more snow falls than melts, from the region below, where the annual melting keeps pace with the snowfall, and where consequently the snow does not accumulate. It does not follow that the snow never melts above the snow-line. As a matter of fact, a considerable quantity of the snow melts there in the summer; but, taking one year with another, more snow falls than melts. The snow-line, of course, is at its greatest height above the sea-level in the equatorial regions, where it is about eighteen thousand feet; in Britain it is about six thousand feet, so that we have no land in Britain covered with perpetual snow; in Norway it is about four thousand or less, according to latitude; and so on, till, in the Arctic and Antarctic regions, we reach the region of perpetual snow at the sea-level. Any land, whether it be flat tableland or rugged mountain, which rises above the snow-line is, therefore, with certain exceptions, such as the peak of the Matterhorn, which slopes upwards at too steep an angle, buried under a thick mantle of ice and snow all the year round. In the summer there is very little snow below the snow-line, which can then be distinctly traced along a range of lofty mountains, as they are looked at from a distance, though at a nearer view the snow region is hidden from sight by the lower fringing hills.

The enormous pressure of this great mass of snow squeezes the crystals close together in the lower portion, and forms them into a compact mass of clear ice; so that a great snow-field consists, for the most part, of snow above gradually passing into ice below. The most favourable conditions, as can be easily found by experiment, for the conversion of snow into ice, is that the snow should be in a melting condition, or that, at any rate, it should not be much below the melting-point. The great pressure itself tends to melt the snow without lowering its temperature, so that the water derived from the snow under such conditions is very ready to freeze again, and so form a solid compact mass. But if the annual precipitation of snow exceeds the annual amount which is thawed, and runs away, there must be some other process going on which gets rid of the excess; inasmuch as it is obvious that, if it were not so, the snow would accumulate indefinitely in these regions. The process is this. The snow of the central and higher portions, acting under the influence of gravity, presses downhill in all directions. Where the slope of the mountain is very abrupt, great masses break away from the edge, and slip or fall down into the lower regions, where they sooner or later melt away. Occasionally these snowfalls, which are called *avalanches*, bury villages beneath them; but generally they fall harmlessly on to the lower mountain slopes or into the upper portions of the valleys. But in many places the slope is gentle, and gradually leads into a valley, down which the ice descends, partly moving downhill by its own weight, and partly pushed by the weight of the ice above it. These long tongues of ice are called *glaciers;* and as they perform very important geological work, it is worth while to study them somewhat closely. The most favourable conditions for the formation of a glacier are, that the valley should ascend up to, or nearly up to, the snow-line, and should have, as indeed most mountain valleys have, a great semi-circular recess at its head ("cirque"), such as has been described in the preceding chapter, and above it a great snowfield. The snow and ice are then forced down the slopes of the cirque and pushed down the valley. The mass of ice and snow which fills the cirque and covers the ground round about it is called the *firn*, or *névé*. It forms the gathering-ground or birthplace of the glacier. If a line be drawn across the valley, just below the cirque, it is evident that, under ordinary circumstances, the quantity of ice which passes this line every year on its downward journey is equal to the amount which melts and flows as a stream of water from the lower end of the glacier. It is also evident that, as a rule, the whole, or nearly the whole, of the glacier is below the snow-line. What distance it shall descend below that limit will depend on the slope of the valley and the quantity of material which is annually forced into it. Many of the Swiss glaciers descend a distance of five thousand feet below the snow-line.

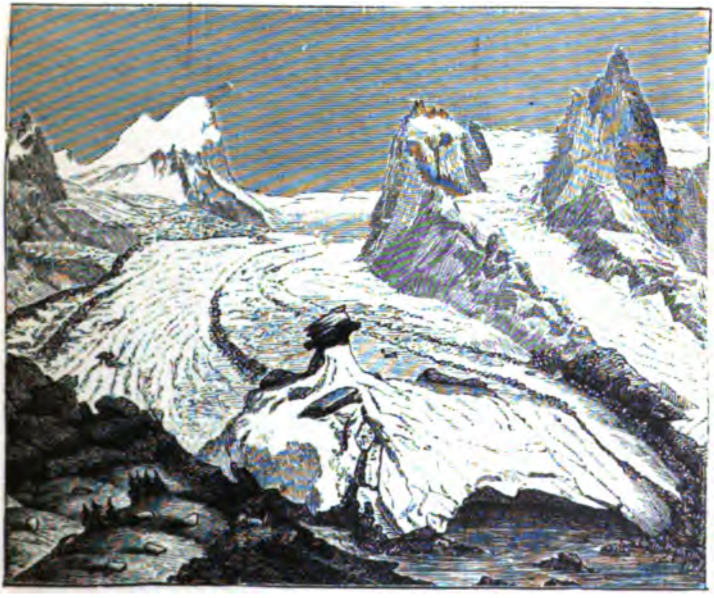


FIG. 60.—A Swiss glacier with moraines.

Although the *cause* of glacial movement is easy to understand, the exact *manner* of it is more doubtful. The two best-known explanations of it are the *plastic* theory, and the *regelation* theory. According to the former, the ice actually flows down the valley like a thick liquid, such as treacle or pitch, would flow; while according to the latter, it progresses by perpetually cracking, slipping, and freezing together again. The fact of the motion, however, is quite certain. Many years ago three guides were lost by falling down a great crack in the upper part of a glacier. Forty years afterwards their bodies were discovered in the ice at the lower end and near the surface. Since then careful and elaborate measurements have been made of glacier motion, firstly by Agassiz and Forbes, and afterwards by Tyndall. Their results show that the motion of a glacier resembles that of a river in every respect except its speed. It moves more quickly in the middle than at the sides or bottom, and the line of greatest movement bends with the bends of the valley, but with a more serpentine curve, always curving towards the concave side exactly as a river does. The rate of motion of any individual glacier varies in different parts, and the rate at the same place varies in different years, being governed by the amount of snow ready to come down. Professor Tyndall found the greatest daily rate of the fastest part of the Mer de Glace to be 34 inches, that of the Aletsch glacier 19 inches, and of the Grindelwald glacier 22 inches. As regards varying yearly rate the Glacier des Bois is recorded to have moved downwards 258 feet one year, and 470 another. The winter daily motion is found to be about half that of the summer.

The unequal movement of different parts of the glacier causes the ice to crack, the central and more quickly moving portion dragging itself, as it were, away from the more slowly moving lateral portion, and developing great cracks, called *crevasses*, which extend across the glacier in curves which present their convex portions towards the upper end of the glacier. These crevasses are continually forming and closing again as the glacier moves onward. They often extend to a great depth, and present a fine view of the inner portions of the glacier which are seen to consist of compact blue ice. The top of the glacier is continually melting; and the water, which at first runs in streams along the surface of the glacier, sooner or later finds its way down a crevasse, and makes its way downwards, trickling along between the ice and the rocky sides and bottom of the valley, and emerging at the lower end as a milky-looking stream, charged with the fine mud which it washes out.

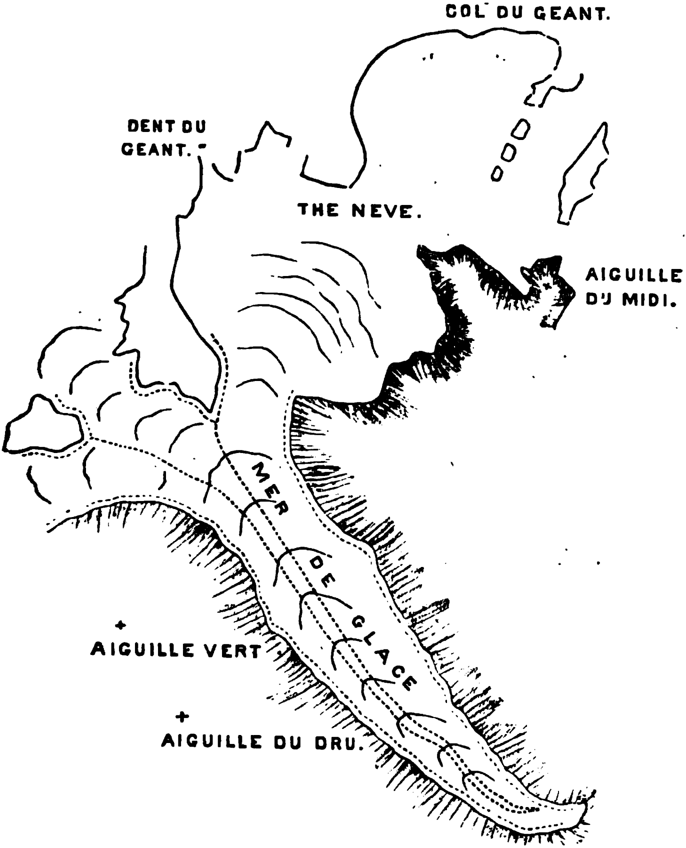


FIG. 61.—Sketch map of the *Mer de Glace*, a great glacier near Mont Blanc. The curved lines across the glacier represent the crevasses; the dotted lines running down it, the moraines. The terminal moraine is at the lower end. The Aiguilles are rocky summits towering high above the glacier.

The sides of the glacier are generally covered with a confused fringe of stones and *débris*, which has fallen down from the sides of the valley. Some of this gets into the crevasses along the margin, and becomes embedded in the icy mass; but a large proportion remains on the top, and the whole is carried onward down the valley. Material of this kind is called *moraine;* when arranged along the margin it is called a *lateral moraine.* Like rivers, glaciers have tributaries; and when a tributary joins a glacier, it is evident that the two adjacent lateral moraines, one belonging to the tributary, the other the main glacier, merge into one which will be continued down the centre. This constitutes a *medial moraine.* It differs from the lateral moraines, as a rule, by seeming to gradually dwindle away as it moves down the glacier owing to portions of it being swallowed up by the crevasses; but this loss is partly compensated by the melting of the surface tending to bring them again to light. A glacier differs from a river in one respect, in that it becomes smaller and smaller as it goes downwards. In its upper portion it fills in the whole valley from side to side, at its terminus it is comparatively narrow. The moraines here are very conspicuous, inasmuch as, while the ice has become less and less, they have increased rather than diminished; so that we find at the terminus of a glacier a mass of gravelly material mixed with huge masses of various kinds of rock from the higher regions. This is the *terminal moraine.* The stream trickles through and among it, and is continually washing out the finer material, and reducing the size of the heap; but it is as continually being replenished. This confused gravelly heap of *débris* is very characteristic of glacial action, and would not be difficult to recognize even if the glacier had vanished. It is not such a heap as a mountain torrent would bring down. It is quite unstratified, the stones are thrown together anyhow, and they do not show signs of having been tumbled about in running water. They are very little rounded and water-worn; the larger masses

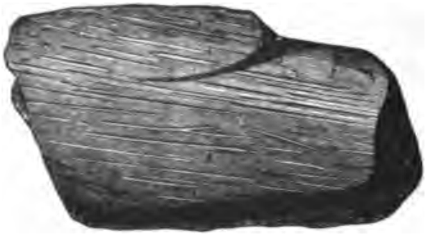


FIG. 62.—A scratched stone from a glacial deposit.

are rough and angular, and in pretty much the same condition as when they crashed down on to the glacier from the overhanging mountains; and many of the smaller stones are rubbed smooth and polished on one side only, while at the same time they are marked with scratches, many of which are parallel to each other. This is no doubt the result of their journey along the bottom of the glacier, where, with one side frozen into the ice, they have been rubbed along among the mud, sand, and stones accumulated between the bottom of the glacier and the rocky bed of the valley. In some places, owing to the melting of the ice and other causes, it is possible to see, and even to descend bodily, between the glacier and the rocky side of the valley which contains it, and in this way information can be obtained as to the effect which the glacier is producing In nearly all cases it is found that the rocks are having their angles and corners worn off, and are being rounded and

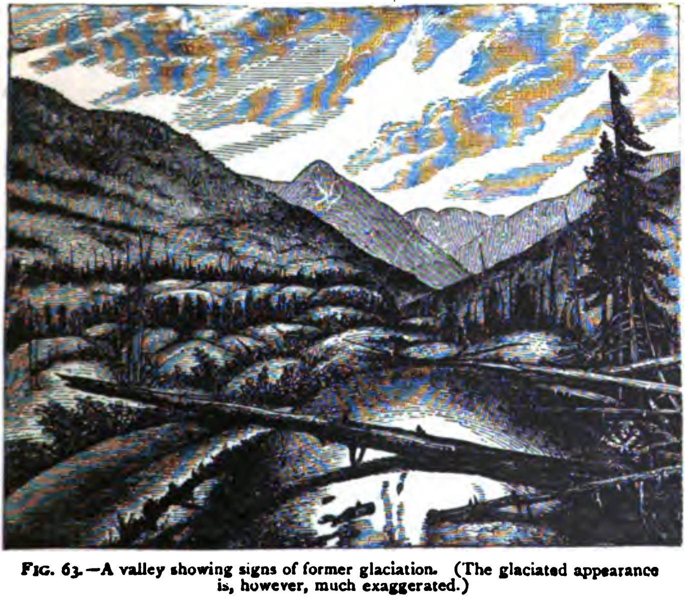


FIG. 63.—A valley showing signs of former glaciation. (The glaciated appearance is, however, much exaggerated.)

polished by the friction of the ice and the fine material frozen into it. And long horizontal scratches may frequently be observed above the level of the present glacier; and lower down the valley, beyond the present terminal moraine, the same phenomena may be seen: from which we conclude that the Swiss glaciers have, at some former time, been larger than they are now. Other evidences of this are scattered remains of terminal and lateral moraines at different points down the valley, and on its sides, with occasionally large masses of rock left in positions difficult to account for on any other theory. These *erratic blocks*, or *boulders*, are found in the lower regions of Switzerland, beyond the mouths of the Alpine valleys, and have even been carried across the intervening plain, and left on the lower slopes of the Jura mountains on the other side. Sometimes these erratics are found poised in precarious positions on the valley sides, where they have been let down and left by the melting ice. When in this position they are known as *perched blocks*. The smooth rounded knobs and masses of glaciated rock have been called by the Swiss geologists *roches moutonnées*, from their fanciful resemblance to the round back of a sheep.

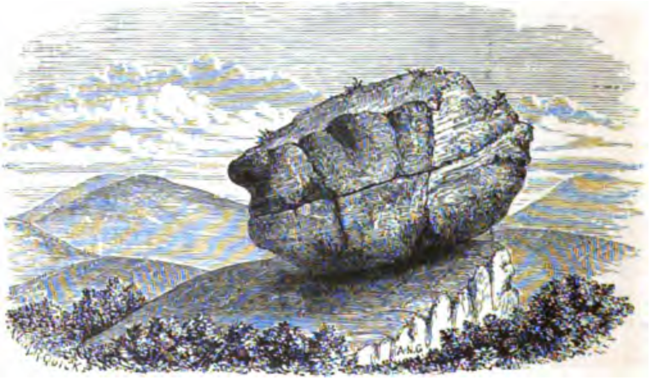


FIG. 64.—Perched block.

It was an important event in the history of English geology when, in 1840, Agassiz announced to the Geological Society that, having come fresh from the investigation of these phenomena in his native country of Switzerland, he had found among the hills of Scotland and the north of England exactly similar appearances, and that he attributed them to the same causes. Smoothed, rounded, and scratched rock surfaces, erratic and perched blocks, and confused heaps and lines of gravel and clay containing scratched stones were familiar to geological observers, but their true meaning and origin had never occurred to any one till then. Before that time geologists were under the impression that the country, and probably the whole world, had at some prehistoric period been swept by the rushing and tumultuous waters of a great flood, and that these deposits and markings were relics of it. Dean Buckland, who was then, perhaps, the best-known English geologist, accepted Agassiz' explanation at once; and both he and Lyell followed up the clue, and proved beyond a doubt that a great part of the British Isles has been covered with an ice-sheet, and their valleys filled with glaciers. Since then further investigations in many parts of the world have made it clear that at one time the Arctic ice-cap extended far southward over Europe and North America, no doubt at the same time that the Swiss snow-fields spread across to the Jura. In the Southern hemisphere also the New Zealand glaciers show signs of having been once more extensive than they are now, proving that a colder climate once prevailed there also. This theory introduces into many parts of the world a very powerful geological agent, which is now inoperative, and at the same time presents a difficult problem for solution. Why an Arctic temperature spread over a great portion of the temperate zone is, however, an astronomical rather than a geological question,

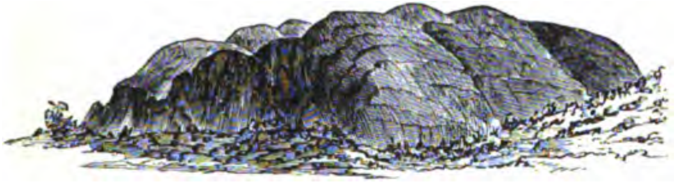


FIG. 65.—Roche Moutonnée.

although attempts to explain it on purely geographical suppositions have not been wanting.

Appearances indicate that while at one time nearly the whole of the country north of the Thames was buried under an ice-sheet, which covered hill, valley, and plain alike, yet at another time it was more limited in extent, and permitted glaciers to form in the valleys—the higher ground being covered with the snow-field, while the lower country was clear, very much as is the case now in Switzerland or Norway. This latter state of things would, of course, obtain while the cold was increasing, and long afterwards when it was again diminishing. The marks of the ice-sheet are quite distinct from those of the glaciers. They consist of scratches and lines on the rocks which, instead of pointing down the valleys, often point across them ; the occurrence of perched blocks in positions they could reach only by conveyance over intervening valleys ; and by the fan-shaped scattering of rocks from some central point. Illustrations of the first of these may be seen nearly everywhere in the north. A good illustration of the second may be seen on the slopes of the mountain limestone hills near Ingleborough, where boulders of Silurian grit, evidently brought across the intervening low ground from the Lake country, are common. And a good example of the last may be seen in connection with a granite hill in Westmoreland, called Shap Fell. The granite contains large lumps of pink felspar, which render it easily recognizable ; and from its home in Shap Fell huge masses of it may be seen straggling over the country to the eastward over Stainmoor, a pass in the Pennines, the stream widening out to the north and south as they get further and further from their point of origin, until they are to be found throughout the whole length of the east of Yorkshire, from the Humber to the Tees. Several may be seen on the seashore near Flamborough Head and elsewhere. Besides this great fan-shaped area, narrower streams of the same granite are found to the north and south of Shap, between the Yorkshire hills in the east and those of Westmoreland in the west.

In many parts of the British isles there occur wide-spreading sheets of a tough clay containing smooth and scratched stones and boulders. This is called *boulder clay*, or sometimes *till*, and was no doubt formed under the ice-sheet, though we are not able so easily to see what is at present going on under the ice-sheets as we are in the case of the glaciers. The boulder clay varies in composition and character, and in the kinds of stones which it contains. It always, however, seems to consist of material which has travelled in a more or less southerly direction from its original position. Besides the boulder clay, many of our hills and valleys, especially in Scotland, are smothered in vast deposits of sandy gravel and stones, which are probably of glacial origin, but have been washed about and rearranged by water, probably derived from the melting ice at the time when the climate was growing warmer.

At the period when the ice age was at its maximum the British isles appear to have been, except perhaps in the extreme south, completely enveloped in ice, in the same way as Greenland is at the present day. It is, therefore, interesting to see what work the Greenland ice is doing. It lies like a thick mantle, apparently hundreds, if not thousands of feet thick over the whole country, and completely obliterates all its physical features. At the same time, it presses downwards and outwards from the more elevated interior in all directions towards the coast, forming, in some cases, broad and extensive glaciers, but generally pushing its way down into the sea without any change of character. Here it ploughs up and greatly disturbs the sea bottom, and, as it intrudes further and further, becomes buoyed up by the water, and finally breaks off in huge masses, and gradually floats away southward, accompanied by ice derived from the "ice foot" or frozen sea margin. Large tabular masses of ice constitute *floes*, the smaller and more irregular ones *bergs*. It is obvious that before leaving the shallow waters of the shore these floes and bergs have often an opportunity of getting frozen into their lower portions any loose rocky material from the coast, and, in some parts, of bearing away *débris* from the cliffs on their surface. There is considerable discrepancy between the accounts of Arctic navigators on the question of the extent to which this takes place, one speaking of millions of tons of *débris*, others declaring they have never observed any. There can be no doubt, however, that a large quantity of material must be borne away from the Arctic shores, and strewn about the bottom of the ocean in the temperate zone when the ice gradually melts. The Antarctic continent presents a long line of ice-bound coast, from which also ice-floes of enormous extent break away and float northward. No doubt a considerable amount of the glacial *débris* of Northern Europe, including the British Isles, was scattered in this way by floating ice, including, probably, the boulders of Shap and other rocks.

Ice often forms at the bottom of rivers. The reason of this is that the whole of the river-water by continually mixing as it flows along is reduced to the freezing temperature, and will turn into ice wherever its current is retarded. This happens at the bottom, and a layer of ice forms there. When it becomes detached, it rises and floats away, and carries much of the *débris* from the bottom with it. In this way the great rivers of Siberia send much material to the Arctic Ocean.

Glaciers also perform another office to which allusion has not yet been made, viz. the making of lake basins. It sometimes happens that an existing glacier causes a lake by closing up the mouth of a tributary valley down which, not a glacier, but a stream of water is flowing. This happens in the case of the often-quoted and described Marjelen See, which lies in the lower part of a valley which opens on to the Aletch glacier, one of the largest glaciers in Switzerland. Here, on a small scale, may be seen ice-cliffs, icebergs, and other Arctic phenomena. Sometimes a glacier which is slowly diminishing in size leaves its terminal moraine, blocking up the valley and ponding back the stream which issues from the end of the glacier; and if the moraine matter is extensive, the lake will be often found in existence long after the disappearance of the glacier. Such lakes exist in the Swiss and Italian Alpine valleys; and there are several in Scotland, as, for instance, Lock Skene, in Dumfriesshire. They are generally small, and many which once existed have destroyed themselves by cutting through the obstructive moraine. In Scotland there are numerous small lakes which entirely lie in hollows in moraine matter and boulder clay, such as the many small lakes of Lewis. But there is a more important class, which includes most of the largest Scotch and Alpine lakes. These lakes are very deep, their bottoms in many cases are considerably below the level of the sea, and they appear to be contained on all sides by solid rock. It is very difficult to understand how and by what known agency they could have been formed unless they have been scooped out by ice, as has been maintained by Sir A. Ramsay. It occasionally happens that earthquake action causes a subsidence which forms a lake-bed; and in old volcanic regions, in Italy and elsewhere, there are lakes in the craters of extinct volcanoes: but such lakes are readily recognized, and are quite distinct from the above. A dislocation of the strata occurring across a valley might cause a rocky obstruction, and so give rise to a lake; but it could, as a rule, be easily recognized, and in the case of most of the lakes in question there is no sign of it. On the other hand, these lakes are almost confined to localities which exhibit marks of glacial action, the margins of the lakes are smoothed and scratched, and their islands are frequently good specimens of *roche moutonnées* on a large scale. We know that moving ice will rise over an obstruction, and it is not difficult to imagine that a descending glacier or ice-sheet would plough out the softer portions of its bed, and produce the rocky hollows.

There are two interesting points of similarity between the structure of the great ice masses and that of the aqueous rocks.

In the first place, the ice is stratified. The snow-fields are often many hundreds of feet thick, and are built up of the snow derived from innumerable falls. They resemble in this way many sedimentary deposits which are accumulated by intermittent deposition. The snow of one fall hardens and alters somewhat in character before the arrival of the next; and in the summer the radiant heat of the sun causes a superficial thaw, the water from which trickles downward among the snow-flakes and again freezes, forming a hard layer. The air which originally fills the interstices between the snow-crystals shows itself in the shape of bubbles, which accumulate according to circumstances at various levels and increase the stratified appearance.

But a more curious effect is the veined structure of the ice, This crosses the lines of stratification at a large angle, and has been shown by Professor Tyndall to be undoubtedly analogous to the cleavage of slate, and to be due to the same cause, namely, lateral pressure. He has found it to be most fully developed in glacier ice just at those points where it has been subjected to most intense pressure through the steepness of the slope or the presence of obstruction. The planes of cleavage are also most marked in the marginal portions of the glacier, where the pressure is great, owing to the more rapid motion of the centre; and they always cross the marginal crevasses at right angles.

From what has been said it is obvious that ice and snow play a very important part as geological agents, both in wearing away the rocks and in transporting and redepositing material, though their mode of action differs in many important particulars from that of water. For example, a glacial clay is a much more miscellaneous substance than the ordinary stratified clay which has undergone aqueous transport and deposition; and the coarser materials are either altogether angular and unworn, or are unequally worn and frequently bear unmistakable signs of their origin. As regards arrangement, pure glacial deposits are quite unstratified; and when stones are found in a clav, as they generally are, they do not lie flat, or in "stable equilibrium," as they would if thrown down by water. Many glacial deposits have, however, undergone rearrangement by water at a subsequent period, and in that case it is not always possible to recognize them. It is not unlikely that a great deal of the stratified clays which are found in some of the geological systems may have been originally derived from old glacial boulder clays and many of the breccias and conglomerates may be rearranged and more or less water-worn moraines.

SUMMARY.—1. The "snow-line" is a surface rising eighteen thousand feet above the earth in the tropics, and coinciding with the earth's surface in the Arctic and Antarctic regions. Upon any portion of the earth which extends above this, more snow falls than melts.

2. From such regions the snow descends either as *avalanches* or *glaciers*.

3. Glaciers are great rivers of ice slowly descending far below the snow-line, and melting as they move downwards. The strain causes *crevasses* to form, and the *débris* from the valley sides forms *lateral moraines*, which by uniting become *medial*, or at the end form *terminal* moraines. The latter are mingled with material from below the ice, including scratched and rubbed stones.

4. The marks left behind by departed glaciers are therefore—

 (*a*) moraines; large blocks of stone in positions otherwise impossible; clay with stones, frequently scratched, embedded irregularly in it;
 (*b*) scratched and polished rock surfaces (*roches moutonnées*);
 (*c*) and probably lake basins.

5. These indications of former glaciers are recognizable in Britain, and in many other regions now free from ice, in both hemispheres, and point to a time when the climate of those parts was very different from the present.

6. In the great ice-fields and glaciers stratification and cleavage (veined structure) may be observed.

QUESTIONS.

1. Describe the crystalline form of water as displayed in snow and ice.
2. What is the "snow-line," and how does it vary with the latitude?
3 What conditions favour the production of glaciers and icebergs?
4. Explain *crevasse*, *perched block*, *moraine*, *névé*, *roche moutonnée*, *till*.
5. In what way would you expect the surface of a country to be affected by being buried for a long period under an ice-sheet? and what marks of the presence of glaciers would be left in the valleys?
6 Explain how "veined structure" of ice is caused.

CHAPTER XI.

THE SEA AS A GEOLOGICAL AGENT.

(*a*) DESTRUCTIVE.

THE sea covers about four-fifths of the earth's surface, and is the final recipient of all the material, both soluble and insoluble, which the rivers bear away from all parts of their basins. The bulk of the sea is so enormous that it has been

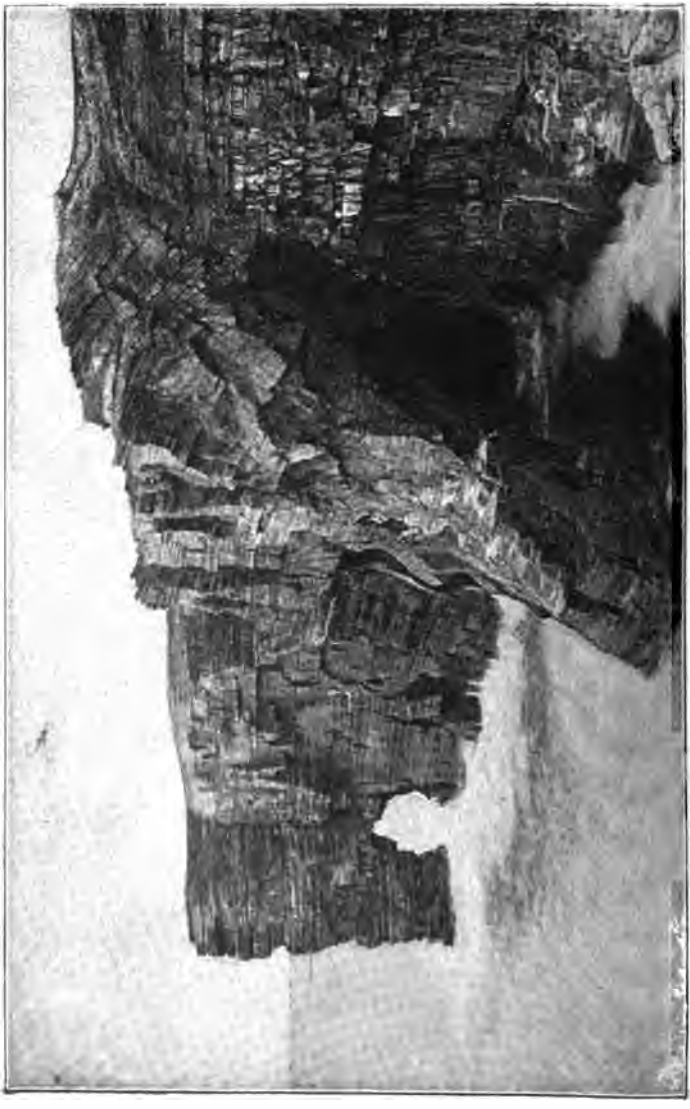


Fig. 66.—Erosive action of the sea on a rocky coast. The "Hole of the Horse" and "Auk Hal'," Rousey, Orkney. (Wilson.)

calculated that if all the dry land were in this manner denuded down to the sea-level, one fortieth portion of the cavity occupied by the sea would be sufficient to contain it all. The action of the sea itself on the dry land, though of a more striking character, and therefore more readily observed, is really much less in its effects than the action of those atmospheric denuding agencies which attack the whole of the surface of the land. The sea only wears away the land along its margin or coast-line, and even there its action is to a large extent of an auxiliary nature, in that it is chiefly occupied in comminuting and disposing of material which has been detached from the cliff above by atmospheric agency, or, if there is no cliff, which has been brought as rain-wash down to the shore. It does, however, exercise a direct action which is more or less restricted to the parts which lie between high and low water. Along this line its action may be compared to a saw making a broad cut into the land, tending to ultimately cut it down to the level of low water. It is greatly aided in this mechanical action by the broken material within its reach, including, on the one hand, large detached rock

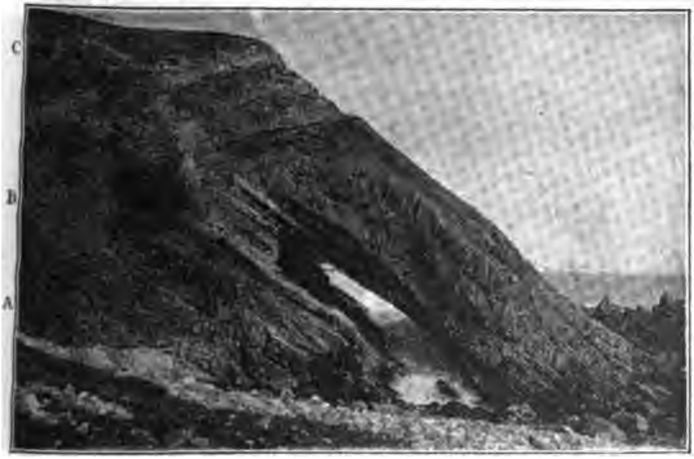


Fig. 67.—The "Whale's Mouth," Cullen. (Wilson.) The sea breaking through inclined strata of quartzite (A), upon which strata of Old Red Sandstone (B) rest unconformably, and Tertiary beds (C) unconformably upon them.

masses, and, on the other, fine sand. The power of the waves to move large stones is very striking. We read of stones seven tons in weight being detached from and hurled over the top of the Plymouth breakwater, and of a mass of rock, estimated to weigh forty-two tons, being moved from its place and hurled among the crags of Barra Head. Stones much smaller than these, employed as battering-rams on the cliffs, day after day, would cause great destruction, both in detaching fresh masses and in breaking up both themselves and others already detached. Smaller stones and sand grains, though individually less effective, do much destructive work on account of their greater quantity and almost continual action. An inspection of an ordinary pebbly beach will easily show the result of this continual washing to and fro. If the cliffs are of hard rock they will frequently be found to overhang their bases, which are cut into by the action above described. At the foot of the cliffs are large and more or less angular masses of rock which have mostly fallen from above; a little lower down is a line of shingle composed of pebbles rounded and smoothed by rolling to and fro; as these are followed away from the cliff they become smaller and smaller, and gradually fade away into sand, which extends below the low-water mark. The loose materials on a sea-beach are thus, as a rule, derived from the adjacent cliff, either from the rock itself or from the loose gravel which often caps it. In some cases, however, it will be found that there are stones on the shore which cannot be accounted for in this manner, but which, by a process shortly to be explained, have travelled along the beach from another locality.

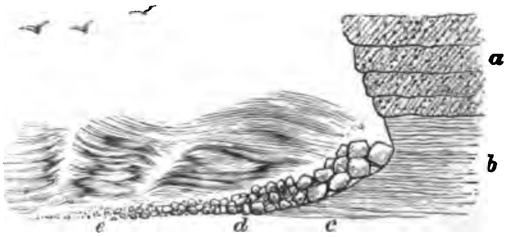


FIG. 68.—Action of the sea on the rocks of the coast. A layer of hard rock (*a*) resting on softer material (*b*). The fallen material very coarse near the cliff at (*c*), finer at (*d*), still finer at (*e*).

The nature of the sea-coast of any district depends on the height of the land surface above the sea at that part, and upon the character and lie of its rocks. Lofty cliffs are an indication that the sea has eaten its way a considerable distance into the land, since it is evident that, when the land was first elevated above the sea, it would, as a rule, rise from the water in a long gentle slope, with its strata sloping upwards into the country. In some cases the sea is found to have cut back the land as far as, and even beyond, its highest point; as, for instance, at Shakespeare's Cliff, near Dover, where an inspection of the ground shows that the cliffs rose higher before it was cut back to its present position, and that the further it is now cut away the lower it will be. Near Brighton, on the other hand, the downs ascend beyond the present line of cliffs, so that there the cliff will get higher the more it is worn backward. In the neighbourhood of Margate and Ramsgate, where the strata are nearly horizontal and the surface of the ground nearly level, the progress of marine denudation does not greatly affect the height of the cliff.

When the strata dip towards the sea, especially if the lower ones are of clay or other soft material, landslips are liable to occur. They are generally caused by water getting down the joints of the upper beds and causing the softer beds below to become wet and slippery. A landslip which occurred near Lyme Regis, in Dorsetshire, some fifty years ago, is a typical case. Here chalk strata rest on gault clay and slope towards the shore, and, after a very wet season, a large section of the chalk along the cliff slipped down over the clay, and fell in confusion on the beach, where much of it still remains (Figs. 69, 70). A succession of similar slips of the same strata have, in bygone times, occurred in the south of the Isle of Wight, in the neighbourhood of Ventnor, and have given rise to the picturesque scenery of the Undercliff. Where the coast consists of hard rock which breaks away slowly, the sea has plenty of time to clear away the *débris*, and so we generally find deep water close in shore, and the waves, at least at high water, washing some distance up the cliffs; but if the cliffs consist of clay, sand, or other loose material which falls or slips down easily and rapidly, then the coast-line is more or less choked with it, and a broad stretch of sandy or muddy beach intervenes between the base of the cliff or shore-line and the water, even at high tide. In this case the sea is so shallow that at low tide the water's edge is sometimes miles away.

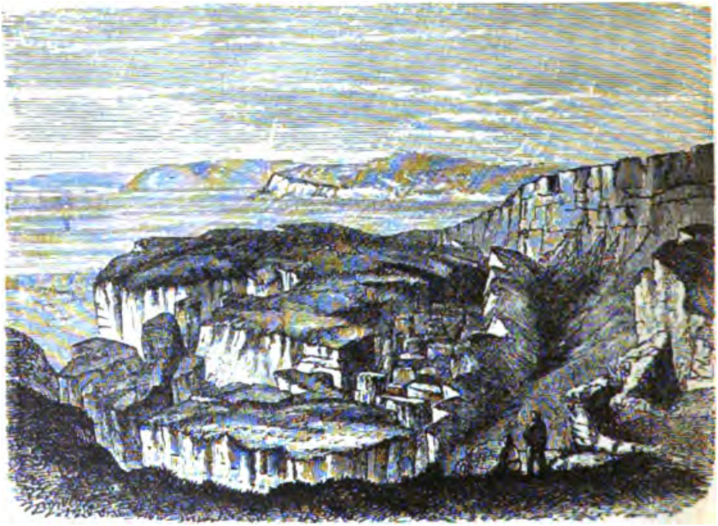


FIG. 69.—Landslip near Lyme Regis.

Even where the rocks are very hard, and where the outline of the coast alters very little during the observation of a lifetime, there are not wanting many proofs of the enormous destruction that has taken place. This is witnessed by the

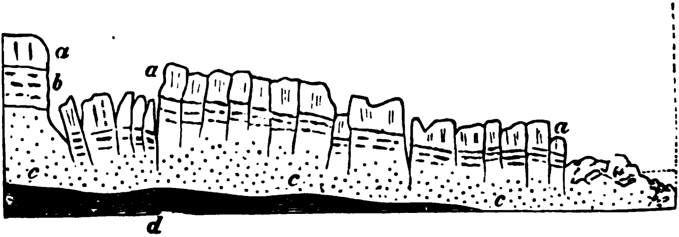


FIG. 70.—Section of the Lyme Regis landslip. *a*, chalk ; *b*, *c*, sand ; *d*, clay.

detached and outlying stacks and rocky islets of the same structure as the mainland which are found fringing rocky coasts. These are especially abundant on the west coast of the British Isles, and down the whole coast of Norway. But it is where the coast is composed of cliffs of sand and clay that the destruction is most rapid. A good example of the former may be seen on the coast of Hampshire between Poole and Lymington, and of the latter in the cliffs of glacial clay which stretch from Bridlington to the Spurn Point, and in the London-clay cliffs of Sheppy and Herne Bay. In many parts of these coasts the rate of waste is put at from one to two yards a year, and the destruction of property both in agricultural land and buildings is very serious. Along the whole length of the Holderness coast the evidences of this may be seen, here a road cut off abruptly by the cliff, there a ruined and deserted farmhouse or cottage awaiting the time when it will go over the receding cliff; and there a field reduced to a narrow strip running along the cliff top. Professor Phillips, writing in 1829, described the old church of Kilnsea as standing near the cliff edge, but it disappeared many years ago. The port of Ravenspur, where Henry Bolingbroke is said to have landed, is quite gone, and no one knows exactly where it stood. Dunwich, on the coast of Suffolk, is another interesting case. This was, in the Middle Ages, an important town with several churches, a hospital, and other public buildings, and is now represented by a ruined church standing near the edge of the cliff, and a few fishermen's cottages. The sandy cliffs of Hampshire between Christchurch and Lymington are in places wearing their way backward into the country very fast. Within the memory of people now living, whole fields have bit by bit gone over the cliff.

It sometimes happens that, in cases such as those above described, the destructive action gradually ceases, owing to a change in the character or dip of the strata, or from the very fact that by their destruction a sheltered and shallow bay has been formed. In other cases the waste is checked artificially by sea-walls, groins, and other contrivances. Thus, at Reculvers, on the north coast of Kent, an ancient and very interesting church with two conspicuous towers used as landmarks, standing within the boundary of a square Roman camp, would, as Sir Charles Lyell predicted, have gone over the cliff years ago, if it had not been saved by lining the cliff with masonry. This was not done, however, before the north wall of the camp and the graveyard of the church had been destroyed.

Bearing these principles and illustrations in mind, it is now very easy to account for the irregularity which is observable in many coast-lines, especially where, as in England, there is a great variety of geological structure. Where the exposure is equal, the hard rocks resist and form the headlands, and the soft ones give way and form the bays and recesses. A rock need not be hard absolutely, to form a cape, but only *relatively* so; the chalk of Flamborough forms a headland because, both to the north and south, the cliffs are formed of soft clay. Nearly all our familiar capes and headlands, such as the Lizard, Start Point, Portland Bill, Beachy Head, and many others, may be accounted for in this way. Some, however, are formed by the accumulation of shingle and sand by tides, waves, and currents, aided occasionally by river action. Such are Dungeness and Start Point. Again, some inlets are river-mouths, and the position of these being determined in another way, they are almost as likely to be in hard rocks as in soft. For example, Plymouth Harbour is an inlet in hard rocks cut by the river Tamar. Islands have been already alluded to. They may be often regarded as capes which have been cut off from the mainland. Some, however, like the Essex islands, are accumulations of mud and sand.

If the sea were, for some reason or other, to be prevented from clearing away the fallen *débris*, it would gradually accumulate, and bank up the cliff, and convert it into a gentle slope. Denudation would then go on more and more slowly, vegetation would in time cover

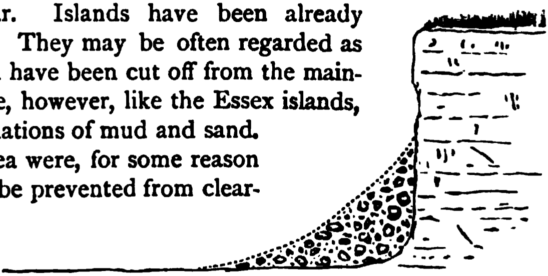


FIG. 71.—Chalk cliff near Walmer, in Kent, deserted by the sea and gradually getting converted into a gentle grassy slope.

it, and it would assume the appearance of an ordinary hill-side. This would happen whether the cliff were hard or soft; in the former case, the change would proceed more slowly. For this reason we rarely see vertical cliffs except on the sea-shore, where the fallen material is perpetually being cleared away. They may be sometimes seen in river valleys, where the river practically does the same thing. In lofty mountain chains, when atmospheric denudation is very intense, we sometimes find immense perpendicular cliffs, but generally it will be found that their fallen material is conveyed away by a snow-field, glacier, or torrent. Instances may, however, be seen of precipices and hillsides being gradually buried in their own waste, the whole of their lower slopes being covered with an immense accumulation of stones which have fallen or rolled from the rocks above. Such a heap is called a *scree.*

The effect of the action of the prevalent winds is an important element in the study of coast-lines. The crests of the waves always form a line at right angles to the direction of the wind, and the waves move forward in the same direction as the wind which causes them. In the open sea the wave is only a rising and falling of the water, as may be seen by its effect on a small boat, or any other floating object at a distance from the shore where the water is deep. The boat merely rises and falls, and the wave passes under it, but the water is stationary. Near the shore, however, it not only rises and falls, but is carried forward with the wave. In the same way the wave washes the stones and sand of the beach forward in its own direction. If the wave is coming obliquely on the shore the stones are carried obliquely also. When the force of the wave is spent, the water flows back from the sloping beach, not in the direction it came, but straight down the slope at right angles to the shore-line, drawing with it many of the stones and much of the sand. The next wave again dashes the material obliquely across the beach, and so the process is repeated again and again, so that the material moves forward in a zigzag course. A change in the wind may cause it to retrace its course, and move back again in the direction it came from, a wind straight off or straight on the shore, or a calm would allow it to remain stationary, but it is clear that it will move one way or the other, or remain untravelled according to the nature of the prevalent wind. No better illustration of this action can be given than what may be observed along the northern shore of the English channel. The general direction of the coast is east and west, facing the south, and the south-westerly winds prevail over all others. In consequence, there is almost an incessant movement of the shingle and other shore deposits from the west towards the east. This movement is in places interfered with by the mouth of a river, or a sudden change in the direction of the coast, and is also sometimes modified by tidal movements. In the case of a river-mouth we find a constant tendency for it to become choked up from the west side, so that the stream is turned aside more and more, and instead of flowing straight out into the sea in the ordinary manner, it turns to the east, and often flows for some distance with the mainland on its left bank, and a long ridge of sand and shingle on its right. This long ridge is entirely due to the cause above described. After a time the exit to the sea becomes so much choked up and encumbered that, in time of flood or in rough weather, the stream breaks through the bank, and the process to some extent begins again. The common mouth of the Stour and Avon in Hampshire, the mouth of the Adur in Sussex, and many of the small rivers of the south coast, are illustrations of this. The great pebble banks which exist in parts of the coast are at least partly accumulated in the same way. The Chesil Bank in Dorsetshire no doubt consists of shingle, much of which has travelled from the stretch of coast from Torbay to Bridport. According to Professor Prestwich it is mainly derived from the destruction of the raised prehistoric beach which once extended along the whole of the south coast. But why did not this

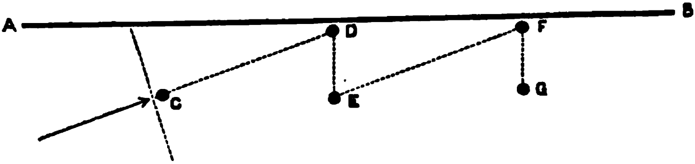


FIG. 72.—To show the movement of shingle in the direction of the prevalent winds. A B, shore line. A wave caused by the S.W. wind rolls the pebble from C to D; the returning wave rolls it down to E. The next wave drives it to F, and it rolls to G, and so on.

shingle continue to travel up the channel instead of accumulating where it has? An inspection of the map suggests two reasons. In the first place, it is obstructed by Portland Bill, round which the coast turns abruptly northward; and in the second place, the coast where the bank has formed is at right angles to the south-west wind, and therefore this wind would be inoperative in moving it further along. The stones have, therefore, remained stationary there, and have, some at one time and some at another, been hurled in stormy weather up out of the further reach of the waves, thus forming the remarkable accumulation of shingle as it exists to-day.

The effect of any obstruction, natural or artificial, in causing an accumulation of sand or shingle is utilized in the construction of breakwaters, groins, etc. These not only break the force of the waves, but encourage the accumulation of material at the base of the cliff, embankment, sea-wall, or whatever protection is needed for.

The difference in character between the eastern and western coasts of the British Isles is very marked. On the east we have low shores, cliffs of clay, sand, and chalk, with here and there lofty cliffs of harder limestones and other rocks; and the sea along the coast is shallow, and greatly impeded by banks of sand and mud. On the west the general character of the coast is much wilder: the rocks are almost invariably very hard, mainly granite, basalt, and slate; the cliffs lofty, rising on the west of Ireland to nearly two thousand feet; and the sea, as a rule, is deeper. If a line be drawn from north to south through the highest parts of Great Britain, it will be found to be much nearer to the west side than to the east. If the chart is examined it is found that for a considerable distance to the westward of the British Isles the sea is comparatively shallow, and that when a certain distance is attained it deepens very suddenly. In this shallow sea there are numerous islands, especially in the portion north of Ireland and north-west of Scotland, and all these islands are composed of rock which appears well calculated to resist destruction by the waves. All these appearances seem to point to the fact that the British Isles once formed a portion of a much larger mass of land, which extended far to the west and north, which was also probably joined to the continent, and that it has been reduced to its present fragmentary condition by the wear and tear of the waves of the Atlantic continued through long ages. The greater fury of the ocean on the west has enabled it long ago to clear off most of the softer strata, and to work its way right up into the highest and most enduring parts of the land; but we can imagine that in time the North Sea will do the same, and there will then remain only a long narrow strip broken into numerous rocky islands, extending to the north and south. These being finally worn away also, there will then remain a nearly flat plain, covered with shallow water, which will represent the worn-off stump of the British Isles. All the solid rocks will still be there, which at present lie below the sea-level; but all the material now above water will be removed, and in the shape of sand, mud, and shingle, will be deposited round the margin, and over the top of the truncated land. Such a level surface, produced by the action of the sea, continually aided by atmospheric agencies, is called a *plain of marine denudation.*

The region known as the "Weald" illustrates this action on a smaller scale. The strata were bent up into an arch as shown in Fig. 73, gradually planed off by the sea to the line A B, and finally, by atmospheric agencies, carved as shown in Fig. 74.

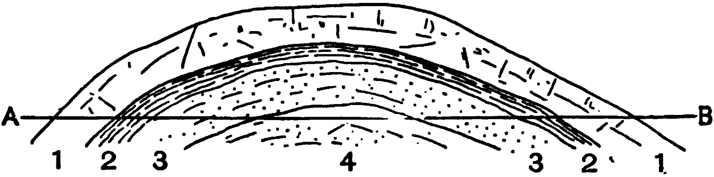


FIG. 73.—The Wealden area, first stage,—elevation of the strata into an arch. 1, Chalk; 2, Upper Greensand and Gault; 3, Lower Greensand; 4, Wealden series.

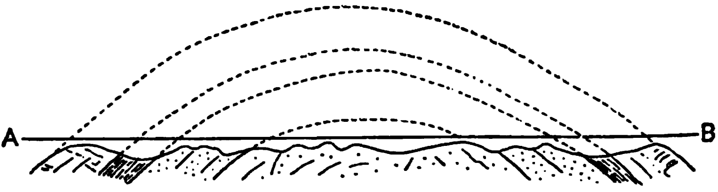


FIG. 74.—The Wealden area after marine and atmospheric denudation.

Such a plain of marine denudation may have laid upon it other marine deposits, and it may be finally elevated above the sea and become dry land again. If so, its comparatively level surface would be again carved out into hill and valley, tableland and plain, by rain and rivers; the sea would again begin to wear away its margin; and the whole round of changes again recur. There is little doubt that in the course of geological progress this has happened more than once, to all the margins at least, of the great continental masses; but owing to the action of other agencies yet to be described, the combined forces of air and water do not seem to have ever succeeded in cutting down the whole of the land below the sea-level. Sir A. Geikie is of opinion that the surface of Scotland has in this way been planed off more than once.

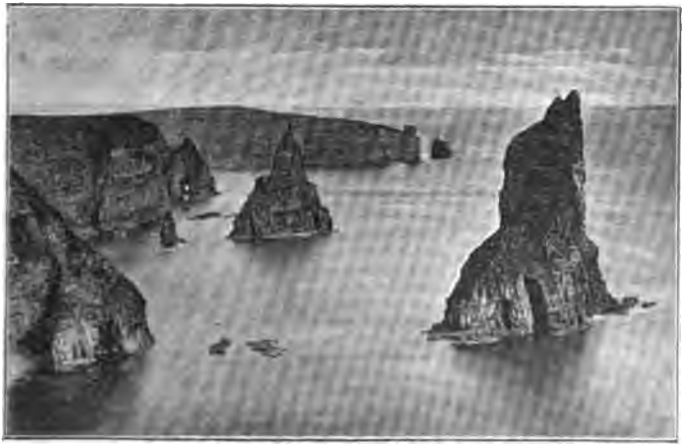


FIG. 75.—The stacks of Duncansby, evidence of waste of coast. (Wilson.)

SUMMARY.—1. The sea covers four-fifths of the earth's surface. As a denuding agent it acts along the land margin only, and there chiefly occupies itself in comminuting and removing the *débris* brought down to it by other agencies. Its direct action is limited to the tract between high and low water mark, and is greatly aided by the sand and shingle.

2. Lofty sea-cliffs, as seen at Dover, Brighton, Ramsgate, and other places, are signs of extensive marine denudation.

The nature of the coast depends on the character and dip of the rocks; and most coast-lines, by their outlying islets, their sheltered bays, and projecting headlands bear witness to long continued waste. Strata dipping towards the sea encourage landslips.

3. A deserted sea-cliff is soon converted into a gentle grass-grown slope when the fallen *débris* is no longer cleared away; and, as a rule, cliffs are only found where the sea or a river washes their base, or where in some way the base is kept clear.

4. Prevalent winds have an influence on the distribution of shingle, causing bars, pebble ridges, etc.

5. The final result of atmospheric and marine denudation upon an area such as the British Isles, is to reduce it to a "plain of marine denudation" by cutting it off to the sea level. This has more than once happened to Scotland.

QUESTIONS.

1. Describe the action of the sea upon a hard limestone coast as compared with one of sand. What is the chief work of the waves?
2. What proofs have we of the former extension of the British Isles?
3 Explain the circumstances which brought about the "Undercliff" in the Isle of Wight.
4. Give a few historical illustrations of coast denudation. How may such waste naturally come to an end?
5 Why are most lofty vertical cliffs confined to the sea-shore?
6. How do you account for the Chesil Bank?
7. Describe the way in which a "plain of marine denudation" is formed.

CHAPTER XII.

THE SEA AS A GEOLOGICAL AGENT.

(*b*) CONSTRUCTIVE.

As nearly all our stratified rocks have been formed in the sea, it becomes necessary to observe very narrowly and carefully the exact methods by which the sea works at the present day, in order that we may see whether it is possible to account for the various kinds of rock, and the conditions under which they exist at present, by processes which are now in operation.

The way in which the sea distributes the waste of the shore has been already described. If the rate of waste is too rapid to permit the sea to thoroughly comminute the fallen material, it is obvious that at the bottom of the deposit there will be a layer of shingle, which, as the beach of one period becomes the sea-bottom of the next, will have thrown down upon it first a layer of coarse sand, then finer, and finally, as the sea eats further and further into the land, a layer of mud. There is thus under normal conditions a tendency for a shore deposit to become finer upwards. The coarse lower beds of shingle, moreover, will lie horizontally upon the worn-off edges of the older strata, which the sea has been cutting down. It is plain, too, that this basement bed of shingle may thus be co-extensive with the plain of marine denudation which is being formed. This agrees with what we commonly see in the rocks, where, as a rule, when there is a break in the succession of the strata, the basement of the unconformable strata is a conglomerate, which is merely cemented shingle. But sometimes we see sedimentary strata, which, from the coarseness of some of the beds, could only have been deposited in shallow water, attaining a thickness of hundreds, or even of thousands of feet, and indeed such is the case in some delta deposits now forming. In these cases we are bound to suppose that there has been a slow depression of the sea-bottom going on, perhaps brought about in some measure by the weight of the superincumbent strata, which just kept pace with the deposition. Other evidence that there are such movements in the earth's crust will be given in another chapter. Shallow-water deposits, especially those formed between high and low water mark, bear many traces of

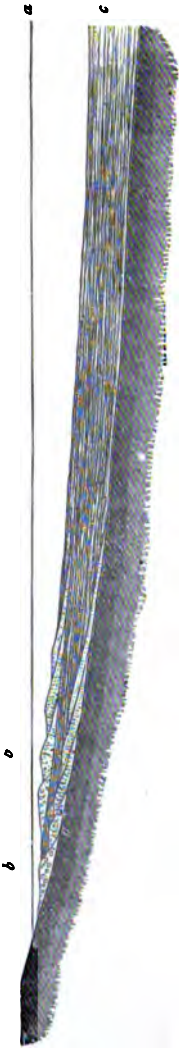


FIG. 76.—Distribution of mechanical deposits on the sea-bottom. *a*, sea-level; *b*, wedge-shaped banks of shingle and sand; *c* regularly-bedded clay.

their origin. Such beds, when out of water, often get their surfaces dried and slightly hardened, so that when they are again covered, and a little more material is thrown down, the contact between the two layers is not perfect, and there is a greater tendency for them to separate along these surfaces than anywhere else. This is particularly the case with fine deposits, such as clay, or mud, or clayey sand, and is the cause of the structure known as lamination. Sometimes, especially in sands and sandstones, the layers are marked by slight differences of colour, even when there is no tendency to split into layers. Other interesting traces which such beds bear are *sun-cracks*, marks made by *raindrops*, and all kinds of *footprints* of crustaceans, birds, reptiles, etc., with *trails* of worms and other marine creatures. Over and above all, they are generally very fossiliferous, and provide us with specimens of the shells and other hard parts of the inhabitants of the shore at the time of their deposition. As these things may be seen in course of formation in any sea-beach at present, so they may be seen in the solid rocks, and they tell us that the seashore of those far-off times was very much as it is now. Another very common structure in the sedimentary rocks consists in what are called *ripple marks*. The surface of a slab of rock when split, instead of being flat, is undulated, like a series of small waves following each other. Such markings may be seen in course of construction any day where the water is gently flowing over a surface of fine sand. The grains of sand are carried forward by the friction of the water until they form a ridge over which they fall. The wind passing over a surface of dry smooth sand has precisely the same effect, but there is very little chance of these being preserved, as the dry grains have no coherence.

It is at the mouths of great rivers that the largest sedimentary deposits are made as a rule. The exact form which the deposit shall take depends on the character of the river, and the conditions under which it reaches the sea; but these matters have been already discussed. It must not be supposed, however, that all the suspended material which rivers bring down is to be found in their deltas. If a little fine China clay is mixed with a pint of water and put away to settle, it will be found to be some days before it has all subsided and the water become clear. In fact, some of the material falls at about the rate of an inch a day. It is evident, therefore, that such material, if brought down by a river, might be carried to the uttermost parts of the ocean if there were currents to carry it; and there is very little doubt that it is so. The Amazon is said to colour the ocean some hundreds of miles from its mouth, and specimens of the sea-bottom dredged up four hundred miles from the African coast have yielded traces of the sediments of the African rivers. The great deposits of mud in a delta are often very homogeneous, and show very little bedding; but where the surface is alternately submerged and exposed the lamination is exceedingly fine, and when the deposit is compressed and somewhat hardened the layers can be peeled off in fine but tough sheets. Mud or clay in such a condition is called *warp*. Tidal currents, flowing first in one direction and then in another, produce a structure called *false bedding*, which can be seen in most beds of sand and in a great many sandstones. It is caused in this way. The current flowing in a certain direction carries the sandy material with it, and piles up thin layers, slightly differing from one another in colour or degree of fineness. These layers slope downwards one over the other in the direction of the current. When the direction of the current changes, the tops of these layers often get cut off and fresh layers brought from the opposite direction are thrown unconformably on the top of them, thus producing an

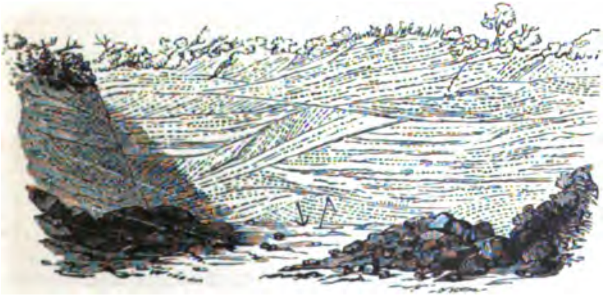


FIG. 77.—Quarry in current-bedded rock.

appearance of small beds, with various degrees of slope, interlacing and replacing one another.

There is one other phenomenon connected with aqueous rocks which may be conveniently explained here. Let us suppose the case of a tract of land which is being slowly let down below the sea-level. As it sinks, the sea gradually encroaches more and more, and the shore deposits gradually overlap and cover each other up. Suppose, for example, at the outset that there is a broad beach of shingle. As the land sinks, the water of the sea permanently covers the shingle, and it gets gradually buried under the finer material which is carried back by the waves. The land continuing to sink, the water deepens, and possibly a bed of limestone forms over the sand. We shall now have sand overlapping shingle, and limestone overlapping the sand, and the whole of the series resting unconformably upon the denuded surface of the rocks composing the submerged land. Such a state of things is called *unconformable overlap*. To some extent it occurs along all shore-lines, but especially when the land is slowly sinking. A very good instance of it may be seen round the Silurian hills of the Lake country, where a coarse red conglomerate rests unconformably upon the older rocks, and is overlapped by the thick beds of the carboniferous limestone. In this case the *overlap* does not indicate lapse of time.

Although there are not wanting instances of wide-spreading beds of conglomerate and of coarse grits, yet, as a general rule, the finer the material the more extensive the strata are. Coarse materials cannot be carried far; while fine material may be carried for almost any distance, and often extends for more than a hundred miles. Among the English strata there are thick beds of clay, which, with very little change in appearance, extend from Dorsetshire to Yorkshire: while it is rare to find a sandstone, especially of the coarser kind, remain uniform for many miles. The distance to which coarse material is carried depends on the current: if the current is variable, then the coarser and finer deposits will overlap and interlace. A flooded river sending a strong current out to sea will deposit coarse material at a place to which it usually carries only mud; and when the river is nearly dried up, the mud will, on the other hand, intrude on the sand. A permanent change might cause a great mass of sand to be thrown down on a muddy deposit, or *vice versâ.* In this way we are able to account for the interlacing of strata of different texture, the change in character of any particular stratum as it is followed across the country, and for the succession which we see in the rocks whose sand or sandstone is followed by shale or clay, and *vice versâ.*

Not only do we find the remains of marine organisms scattered through the sedimentary rocks, but there are rocks forming in the sea almost exclusively built up of their remains. Most of these are formed in comparatively shallow water. Perhaps the most important of these are the coral limestones which are now forming along the coasts of many tropical countries, and of which many of the smaller tropical islands are entirely composed. The reef-building coral polypes can only flourish where the water is warm, clear, and not very deep; but when these conditions exist they form immense reefs, which may, like the Great Barrier reef of Australia, extend for hundreds of miles along a continental coast, and which generally encircle all the islands within the tropics. We have in the British Islands several limestones which have evidently been coral reefs; and their presence so far from the equator either means that the coral species of which they are composed could thrive in colder climates than their successors can at the present day, or that the climate here was, at the time of their formation, warmer than it is at present. The latter supposition is not at all unlikely. As with other rocks, the coral is continually being broken and comminuted by the waves, and converted into shingle and coral sand; and the coral sand, with embedded fragments of coral and shells, is again frequently, by the action of percolating water depositing carbonate of lime, becoming converted into a limestone rock harder than the original coral. The Bermudas are entirely formed of coral sand and rock formed in this manner.

Most of the limestones are formed in more or less clear water, for the simple reason that in water containing and depositing mud or sand the shells would eventually merely figure as fossils in sandstones or shales, whereas, when there is no sediment accumulating, a deposit of shells only is formed. Along the shore, between high and low water marks, the prevalent shells are those of the periwinkle, cockle, mussel, and limpet; the next zone, from low-water to about fifteen fathoms, generally produces a large growth of seaweed and oysters; at a greater depth are the larger gasteropods, such as the whelk; beyond that, the less familiar brachiopods and deep-water corals; while in the depths of the ocean shells and other organisms are small, and few both in individuals and in species, though specimens of most of the leading classes may be found, including siliceous sponges, mostly of the stalked kind, corals, and various molluscs. As the conditions at the bottom of the deep ocean are fairly uniform throughout the world, the abyssal fauna varies much less through great distances than that nearer the surface, although it is not at all uniform throughout the ocean-bottom. This has been proved by the deep-sea surveys made by the *Challenger*, *Blake*, and other expeditions, which show that the deep-sea fauna is certainly not entirely unconnected with that now living on the shores nearest to it. Wherever circumstances are favourable for the multiplication of any particular species, there, of course, their remains will predominate and give a special character to the resulting limestone. Thus just as at present extensive deposits of oyster shells accumulate at one place, and cockle, mussel, or periwinkle shells at others, so it happened in past times, as is proved by the existence of the *pentamerus* limestone, *encrinital* limestone, and such strata as the Purbeck and Sussex marbles, full of shells of *planorbis*. Owing to the varied conditions of climate and food-supply, the shore and shallow-water fauna varies much more than that of the ocean depths; even when the superficial appearance is the same, there are minute differences which distinguish the inhabitants of cold, temperate, and warm regions from each other; and even where the general conditions are the same, the species, as a rule, differ if their areas are far apart or separated from each other.

The abyssal fauna being very scanty, and the amount of sedimentary matter which is carried out to the central and deepest parts of the ocean by currents being almost infinitesimal, it is interesting to learn the character of the deep-sea bottom far removed from land, as described by recent surveys, particularly that of the *Challenger*. They report that the bottom of the sea which fringes the land to a distance of about 150 miles is covered with sedimentary material. When the water is more than a hundred fathoms deep this material consists of a greenish or reddish coloured mud, containing small particles of quartz, flakes of mica, grains of glauconite, etc. Round the shores of volcanic islands are fine volcanic products, forming a greyish mud; while round coral islands there is light-coloured coral mud. As the deeper water is reached, these deposits merge into a fine impalpable greyish ooze or silt, in some places almost or quite amorphous, and at others largely consisting of readily recognized whole or broken shells of foraminifera and other minute organisms, mixed with spicules of siliceous sponges, spines, and tests of deep-sea encrinites, diatoms, and here and there a fish-tooth. The basis of the whole mass is the foraminiferal mud; and from the prevalence of one particular species, it is known as the *globigerina ooze*. In a few places this ooze is replaced by others, as in the central and western Pacific, where the siliceous skeletons of radiolaria predominate, and constitute what is known as the *radiolarian ooze;* while further south, down to the Antarctic ice-sheet, is the *diatomaceous ooze*, largely made up of the siliceous tests of diatoms. At most depths, however, beyond two thousand fathoms these muds give place to an exceedingly fine clay, generally red or chocolate in colour, owing to the presence of oxides of iron or manganese, but varying very much in composition in other respects. As the foraminifera, whose remains are so abundant in the ooze, are found in the surface waters of the ocean, their absence from the clay can only be accounted for by supposing that, before they have time to reach such a great depth, they are all dissolved in the sea-water, and that the red clay represents the residue of insoluble matter which has succeeded in reaching the bottom. Both this deposit, the ooze, and the shallow-water formations receive accessions from the volcanic and meteoric dust, which appears to be carried in a finely divided state all over the earth, in the upper currents of the atmosphere; and the deeper deposits must occasionally receive accessions from the droppings of icebergs and floes in the manner previously described. The globigerina ooze is not, in some respects, unlike chalk; and it was, when first discovered, often spoken of as chalk in course of formation; but a closer examination reveals several points of difference. For instance, the ooze, when dried, contains from 40 to 80 per cent. of carbonate of lime; while chalk contains about 97 per cent. The fossils of the chalk also indicate that it was accumulated in comparatively shallow water. Chalk, however, like the ooze, is largely composed of foraminifera, and it is interesting to notice that occasionally masses of clay and stones are met with embedded in the chalk in a manner which strongly suggests a deposit dropped from floating ice. Every kind of shore deposit now known to be forming can be found represented in the solid rocks; something analogous to the deposits of the intermediate depths is known: but, with perhaps an exception at Barbadoes, no rock is known which can be paralleled with the red clay of the deep ocean. This suggests the inference, which is strengthened by other considerations, that the depths of the oceans are permanent, and have never been converted into dry land, and hence that no dry land has ever been so deeply submerged as to form the bottom of the central ocean. In other words, the great oceans and the great continents are permanent; the geological changes of land into sea and sea into land have only taken place along the margins.

Deposits formed in lakes differ in some respects from marine deposits. Fresh-water shells often abound, and where fine sediment accumulates slowly they form a considerable proportion of the deposit, which forms a fine marl, or *shell-marl*. Frequently, also, layers of peat intervene, and water-logged vegetation of all kinds brought down into the lake is much more likely to get preserved than if it is carried into the sea. Many fresh-water deposits, notably some in Switzerland, contain beautiful and varied collections of fossilized leaves.

Along the sea-margin the evaporation of shallow lagoons often causes the accumulation of salt, while still larger deposits are forming in places where, as in Central Asia, there are large salt-lakes. Gypsum is deposited under similar conditions; but as beds both of salt and gypsum are very characteristic of the Trias, they will be most conveniently described and discussed in connection with that system.

SUMMARY.—1. By watching processes at work on the sea-beach we may learn why overlying, unconformable strata generally have a conglomerate base and become finer upwards; and the various markings found on slabs of stones, such as sun-cracks, ripple-marks, rain-pittings, footprints, etc., may be seen in process of formation. False-bedding, overlap, and lamination are also readily understood.

2. We also learn why clays and shales change less in character than sandstones, why different rocks alternate with each other, and how the different limestones are formed.

3. The deep-sea fauna, though somewhat varied, is limited in species and individuals, and appears to be derived from, or allied to, that of the nearest shallow water; though, owing to the uniformity of deep-sea conditions, the range in space is much greater than that of the shallow-water fauna.

4. Deep-sea deposits may be thus classified:—

(*a*) a *littoral* and a broad *marginal deposit*, mainly derived from the land, succeeded by—

(*b*) the *globigerina ooze*, replaced locally by *radiolarian* and *diatomaceous* deposits;

(*c*) below two thousand fathoms, the *red clay*.

5. Fresh-water, chiefly lacustrine, deposits are recognized by their special shells, peat beds, and vegetable fossils, often including a great variety of leaves.

QUESTIONS.

1. Explain clearly the formation of a wide-spreading basement conglomerate.

2. Describe the formation of *false-bedding*, *warp*, *overlap*.

3. How may coral be converted into a compact limestone showing very little trace of its origin?

4. Describe the general character of the deep-sea fauna.

5. In what respects does globigerina ooze resemble and differ from chalk?

6. What proofs have we that the deepest parts of the oceans have never been dry land?

7. How is the absence of foraminifera from the red clay to be explained?

8. How may a fresh-water deposit be recognized?

CHAPTER XIII.

FOSSILS.

A VERY superficial examination of the stratified rocks, whether sandstones, limestones, or shales, whether in cliffs, quarries, or hillsides, or even in the walls of our buildings, soon brings to light the fact that they contain shells and occasionally bones, teeth, and other animal remains, together with what appear to be twigs and branches of trees, and more or less perfect impressions of leaves and ferns. These things must have been observed from the very earliest times, and thoughtful people must often have pondered and speculated on their meaning. In these days no intelligent person could possibly doubt that these remains are really portions of plants and animals which were once alive. Many of the shells embedded in the rocks are as perfect and life-like as those which can be picked up on the sea-beach at the present day. But two or three hundred years ago there seems to have been a fixed idea that the earth was created and sprung into being much in the same condition as we see it now, and that therefore the fossils could not possibly be remains of real plants and animals. All manner of strange and wild notions were propounded. These stony matters which mimicked organic nature were the result of the "fermentation by heat," of a "materia pinguis," of the "tumultuous movements of terrestrial exhalations;" they were mere "earthy concretions" which assumed their peculiar shapes under the influence of the heavenly bodies; they were "sports of nature" vegetated by the force of "an internal principle," and so on. In time, however, the true explanation gradually prevailed. Steno, a Dane resident in Italy in the seventeenth century, and who has been before alluded to, demonstrated that certain remains were exactly like those of creatures still living in the Mediterranean, and, moreover, that the strata in which they were embedded were evidently formed of materials derived from the waste of other rocks. He discriminated, by means of their fossil contents, between marine and fresh-water deposits, and argued that inclined strata were ·rinally horizontal.

In those days it was firmly believed, however, that the Bible contains a full and exact account of the origin and history of the earth from the beginning of time; that the earth was called into existence and made ready for man in a very brief period some six thousand years ago; that before then it had never been inhabited; and that since that time it has been under water only once, viz. during the deluge in the days of Noah. Consequently Steno tried to persuade himself and others that the remains embedded in the rocks were those of creatures killed and buried by the Noachian flood; and he pointed out, quite inaccurately, that only the uppermost rocks had fossils in them. This belief vaguely prevailed till a much later period; and in the beginning of the present century it was a prevalent belief that, at any rate, the remains of the huge and strange animals which are so abundant in the Post-Tertiary strata, and which are nowhere found living on the earth in the present day, were really killed off by the flood. For that reason they are still often spoken of as "antediluvian animals." Until Agassiz brought forward the idea that the British Isles had been covered with ice, it had been the custom to group together many of what are now known to be glacial deposits, under the title "diluvium;" the idea being that they had been left by the waters of the Flood when they rushed tumultuously over the earth.

When the rocks began to be carefully studied, two difficulties at least presented themselves in connection with the diluvial theory of fossils. In the first place, it was discovered that if all the various layers of rock which are found lying on the top of one another in regular succession were placed in order in a great vertical pile, this pile would be several miles thick, and would contain hundreds of layers of various limestones, sandstones, shales, clays, etc., alternating with one another, fossils being present in nearly all of them, and not merely, as Steno thought, in the upper ones. It was obviously absurd to suppose that all these rocks could be laid down one on the top of the other in less than a year, as had been once supposed. Moreover, by this time the direct study of nature had taught how rocks are really formed, and are being formed at the present time, and what a slow process rock-making is.

In the second place, it was discovered that, though there are fossils nearly everywhere in this great succession of rocks, yet the fossils are not everywhere the same. If a group of beds be examined, for example, near the top of the series, and the fossils collected and studied, and if then the same thing be done in the middle, and again towards the bottom of the pile, it will be found that these three collections of fossils are very different from each other, and have very little in common. Those from the upper rocks will be found to be rather like, and in some cases identical with, the remains of animals and plants which are living now on the earth. Those from the middle portion will be much stranger in appearance, and will contain many forms quite unlike anything living now; and out of several thousand different fossils which could be collected, none will be exactly like the forms living at present. Those from the lower portion will be stranger still; and many forms of life which are abundant now, such as all vertebrate animals and flowering plants, will be altogether absent. On examining still more closely it will be found that every separate series of rocks has its own special group of fossils, by which it may be recognized. They will not, as a rule, be all different from those in the beds above and below, but some of them will; and by the presence of these, and by the relative abundance of others, that particular set of strata may be identified without the necessity of looking to see, or when it is impossible to see, what rocks are below or above it.

This is the most wonderful and the most important discovery that has ever been made in the history of geology. It was made and published about a hundred years ago by Mr. **William Smith**, an English surveyor, who for that reason is often called the "father of geology." It thus gradually dawned upon men's minds that, in the great series of stratified and fossiliferous rocks, we have a kind of museum, arranged chronologically, exhibiting to us the remains of the creatures which have inhabited the earth at various successive epochs. By this means all these rocks have been divided into groups, the groups into systems, the systems into smaller divisions, and these again into still smaller, but each containing its own special group of fossils, and each representing a distinct period in the history of the earth. The explanation of how such a state of things has been brought about, why the life of the earth should apparently be in a state of perpetual change, will be the subject of another chapter.

The word **fossil** simply means something "dug up," but it is always understood to mean some plant or animal substance in a more or less altered condition, or traces of it, which have been embedded in the rocks. It may have been lying on the seashore, and have been buried in the marine deposits formed there, or in the wind-formed sand-hills, or washed down by a river and buried in the silt at its mouth, or in the alluvial deposit in its valley, or it may have been buried in the mud at the bottom of a lake. Or, again, it may have been encrusted over and embedded in the deposit of a petrifying spring, or in the stalagmite on the floor of a cave, as has happened to the bones of many carnivorous cave-haunting animals, including man himself. Peat-bogs have the property of preserving in a very perfect condition the bodies of animals, and stumps of trees, and any other things embedded in them. The dust and ashes from volcanoes, especially when they fall in the sea, often entomb the remains of plants and animals. Some marine shell-fish live in great colonies, and form immense layers of shells in the shallow waters along the coast without any other material at all, forming limestones, which, as a rule, are simply masses of fossils more or less perfect. Some would even consider as fossils the relics of primeval, uncivilized man, his implements of stone and bone, his ash-heaps, his buried canoes, and all the numerous marks of his presence which he has left behind, and, in fact, they would strictly come under the definition already given. Indeed, it is difficult to draw the line and say what shall be the limit. Generally, however, though not invariably, we do not apply the term *fossil* to any object which is embedded in a deposit still in course of formation. For instance, we find two oyster shells, one in the sand on the seashore, and the other in the sand of the cliff which the sea is at present engaged in wearing away. The latter we should call a fossil, and the former not.

A fossil may be *the actual organism* itself, pretty much as it was at the moment when it was entombed. This is the case with flies and other insects which are often found embedded in amber. The amber is itself a fossil, being the gum which has oozed from the trunk of a tree; and the flies which it contains alighted on its sticky surface, and were embedded before they could escape. Coal is also fossil material, but it has been much altered by compression and by the loss of certain of its constituents. In other cases the original substance has entirely perished, and we only find its impression or cast. This is often the case with leaves of plants and fronds of ferns, which have been embedded, perhaps, in a fine soft mud at the bottom of a quiet lake. The mud has gradually hardened into stone, and at the same time the leaf has decayed and been completely removed; but its impression is stamped on the stone, and exhibits in the most perfect manner every detail in the marking of the original leaf. Again, a shell may be similarly embedded. The soft body of its original occupant soon decays and gets removed, generally before the shell is buried, and its place is taken by the mud. Several things may now happen. The shell may remain unaltered. In this case, on breaking open the rock we should find, firstly, the shell; secondly, a cast of the outside of the shell stamped on the interior of the cavity in which the shell was lying; and thirdly, inside the shell we should find a lump of hardened mud or stone which would supply us with a cast of the interior. If the rock in which the shell is embedded is hard stone, we should not be very likely to succeed in separating the shell, the external cast, and the internal cast; we should probably be content with getting out the shell complete, and leaving its internal cast in it. Generally, however, when a shell gets embedded in this manner it does not remain complete and unaltered. A shell consists mainly of carbonate of lime, and as water percolates through the rock it is very likely to dissolve the shell, and carry it all away in solution. In this case, on breaking open the rock we should find the external cast, and in the cavity the internal cast, either lying quite loose or attached. Many rocks are full of cavities due to this cause. Again, instead of the cavity from which the shell has been removed being left empty, some material may be deposited in its place, often silica, and sometimes even carbonate of lime itself. In this case, although the material would exhibit every minute marking on the surface of the shell, and would give a perfect idea of its shape, it would not, as a rule, have the same internal structure. Sometimes, however, the deposition of the new so exactly keeps pace with the removal of the old material, that not only the external form and appearance is preserved, but the minute internal texture, even when examined under the microscope. This is often the case with specimens of fossilized wood. They have the appearance of wood, but are really silica or flint. If a thin slice of the interior is cut and examined with the help of the microscope, it looks exactly like wood. Some fossils are largely replaced by iron pyrites.

The history of the life of the world which is got from the study of fossils is, after all, by no means complete. The animals themselves are rarely preserved for us, only their shells or bones. It therefore follows that those creatures which have no hard part have left no record for us at all. Such things as sea-jellies, worms, anemones, slugs, and many others come under this head. Of them we learn next to nothing. Then, again, inasmuch as the great majority of our fossils are embedded in rocks which were originally formed in some lake or river, or on the seashore, it follows that some creatures have had a much better chance of being preserved than others. A bird, for instance, has bones as well as a fish, but we find many more fossil fishes than fossil birds. In fact, fossils of land animals are comparatively rare, while those of water animals are common.

The most common and perfect of all are those creatures which had a hard outside shell or skeleton, and lived in comparatively shallow salt water. These got embedded, after death, in the various deposits already described, which were formed along the seashore. Such are shell-fish, crustaceans (lobsters, crabs, etc.), and sea-urchins, specimens of which are not only abundant but often extremely perfect.

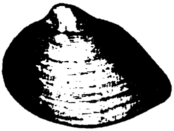
Again, whole periods of the earth's history over large areas are not, so far as is yet known, represented by any fossiliferous rocks; that is to say, we have not found any rocks which were formed at that particular period. For example, after the chalk was formed, a long period seems to have elapsed before the deposition of the beds which, in England, rest on the top of it. A few deposits are known on the continent of Europe which were formed in the interval, but these do not add much to our knowledge of the history of this part of the earth during this long period.

Many fossils, even after they have been safely embedded in the rocks, have in various ways been destroyed.

They may have been dissolved or destroyed by metamorphic action, or carried away in the course of the denudation of the rocks containing them. By this latter means a very large proportion has been lost, especially those in the older rocks, of which a small fraction only now remains.

The history, therefore, to be got from fossil evidence is imperfect. It has been compared to a history of England which, to begin with, was not a complete record of events, and which has had many leaves torn out completely or partially, and some blotted and more or less obliterated. From such a book we could get some idea of the course of events; but while our knowledge of some periods might be pretty complete, of others it would be imperfect, and of some we should know nothing at all.

Cyrena.



Planorbis.

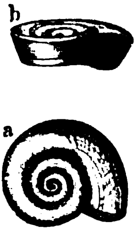


Fig. 78.—Fresh-water shells.

Not only can a more or less perfect history of animals and plants be compiled from these "records of the rocks," the fossils throw great light upon the conditions under which the deposits containing them were formed, and hence upon the geography of the time. For example, there are certain shells which belong to creatures which live in fresh water, and although, as has been said, most fossils belong to species which are now extinct, yet, nevertheless, there is, especially in the more recent fossils, a sufficient resemblance to enable those who have studied these matters to recognize them as belonging to the fresh-water kind. If, therefore, a rock contains such shells in any quantities, and none of those which belong to the sea, we are enabled to say that the rock was probably formed in some lake, and certainly not in the sea. Similarly there are certain forms peculiar to slightly salt water, such as that of the Baltic and other inland seas which have great rivers pouring fresh water continually into them, and at the mouths of rivers; and there are others which frequent the shallow water of the seashore, others the deeper water, and so on. Similarly with regard to climate. Many marine shell-fish and other organisms live only in cold water, others in the warm water of the Tropics. If we find Arctic shells in some of our English strata, and palms and turtles in others, we conclude that at one time the climate was colder than now, and at another hotter.

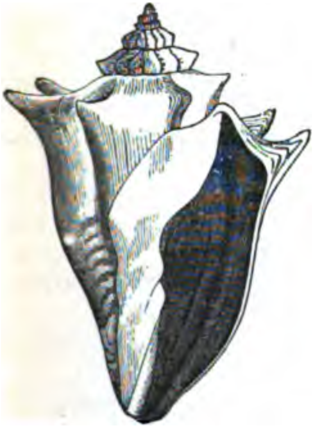


Fig. 79.—Voluta (warm water).

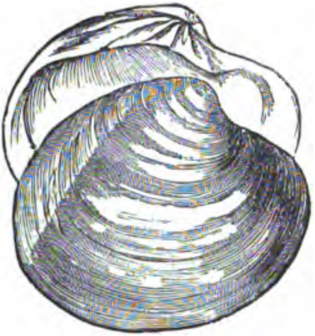


Fig. 80.—Cyprina Islandica (cold water).

SUMMARY.—1. Remains of plants and animals were observed in the rocks in olden times, and all sorts of strange conjectures were made to account for them. The favourite opinion was that they got there in the time of the Flood, but this idea was gradually dissipated when it was seen (1) that they occur in hundreds of strata, miles in total thickness; and (2) that they are not always the same, but that each group of rocks has its distinctive fossils. Then it was realized that they represent a long series of phases in the natural history of the earth.

2. Fossils are the remains or traces of the remains of plants and animals embedded in the rocks.

They may be—
   - (*a*) the *original* unaltered organism, or a part of it;
   - (*b*) a *model* produced by displacement, which may or may not exhibit the original texture;
   - (*c*) a *cast*, internal or external.

3. The fossil record is imperfect because—
   - (*a*) organisms are preserved unequally;
   - (*b*) only a few of those that are preserved are accessible to us;
   - (*c*) many have been obliterated by denudation or metamorphism.

4. Fossils give information about the rocks which contain them:—
   - (*a*) whether it is a salt or fresh water deposit, shallow or deep;
   - (*b*) as to the climate of the period.

QUESTIONS.

1. What hindered people in the Middle Ages from understanding the real nature of fossils?
2. What did (*a*) Steno, (*b*) William Smith, teach on the subject?
3. What animals and plants have the best chance of becoming fossilized?
4. Of what may a fossil consist?
5. What difficulties are there in the way of getting a full history of life from fossils?
6. Why do we find so many shells in the rocks?
7. How, from fossils, can be learnt something about the climate and geography of the period?

CHAPTER XIV.

THE INTERNAL HEAT OF THE EARTH AND ITS EFFECTS.

We have seen that the tendency of the geological agencies which we have hitherto considered, is to reduce the whole surface of the earth to a dead level just covered by the sea; to form a great "plain of marine denudation," with stratified deposits of shingle, sand, and mud spread out all round its margin. Stratified deposits many miles in thickness have been formed, deposits which bear witness to a lapse of time almost infinite in extent, yet the earth is far removed from the condition to which these denuding forces tend to reduce it. Mountains stand up more than five miles, and great table-lands two and three miles above the sea-level. There must evidently be some other agency acting in opposition to these aerial and aqueous forces which prevents the earth from getting levelled. Before considering theories on the subject it will be well to examine any facts which present themselves.

The first and most noticeable fact is that much of the earth's surface, even on high table-lands and mountains, is composed of aqueous rocks which have evidently been formed in the sea, as we can see by their texture and by their fossils.

In many parts of the coast of Britain there are deposits of sand and shingle containing remains of marine shells, lying high above the reach of the sea, and if it is a rocky coast there will sometimes be, as in Fife, an inland cliff containing sea-worn caves, and the face of the rock may contain borings made by Lithodomi, and other boring marine shell-fish. Such raised beaches are common in all parts of the world. Several have been described in Chili, others in Norway and Spitzbergen, and there are many cases round our own coasts.

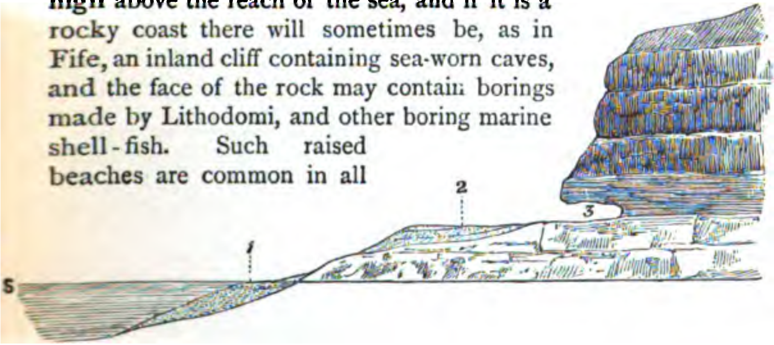


Fig. 81.—s, present sea-level at high tide. 1. Present sea-beach. 2. Old sea-beach. 3. Old sea-cave.

Another proof of change of level is derived from the condition and distribution of coral reefs and islands. Some coral islands are considerably above the sea, which is a proof of elevation of the sea-bottom from which the island rises. Others are practically at the sea-level, the slight elevation of the interior being due to the accumulation of vegetable soil and the blowing of the coral sand from the beach. Islands of this class generally form a more or less broken and irregular circle, and enclose a land-locked lagoon, where the water is comparatively deep. Such an island, or circle of islands, is called an *atoll.* As they occur in the midst of the Pacific, the largest ocean in the world, it has been a puzzle to know how they were originally formed, as the reef-building coral polyp cannot live at a greater depth than twenty or thirty fathoms. Two explanations have been put forward. The oldest and best known is that of Mr. Darwin. He imagined that originally there was an island, probably volcanic, where the lagoon now is, and that a coral reef was formed round its coast where

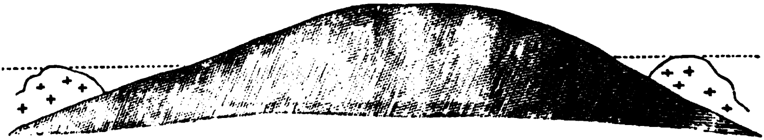


FIG. 82.—First stage. The island with its reef near the shore, called a *fringing reef.*

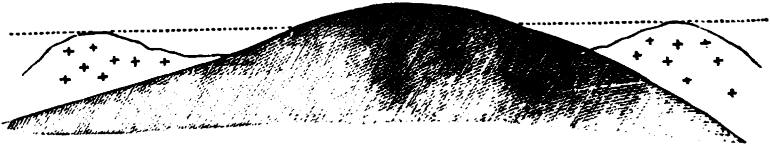


FIG. 83.—Second stage. Much of the island submerged, and the reef now further from the land, but built up to the sea-level, and keeping pace with the submergence (*barrier reef*).

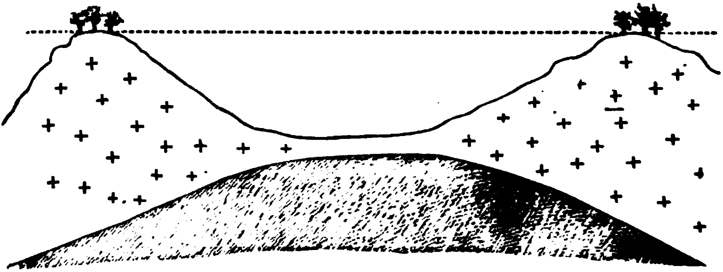


FIG. 84.—Third stage. The island quite submerged, and the reef converted into an *atoll.*

the water was of suitable depth. He supposed that the island then began to sink, owing to a gradual lowering of the sea-bottom, until finally it disappeared, leaving only the reef, which had been growing continually upward while the island was going down. Mr. Darwin, therefore, considered that those parts of the ocean where there were atolls were regions of subsidence. Figs. 82–84 will explain the various stages.

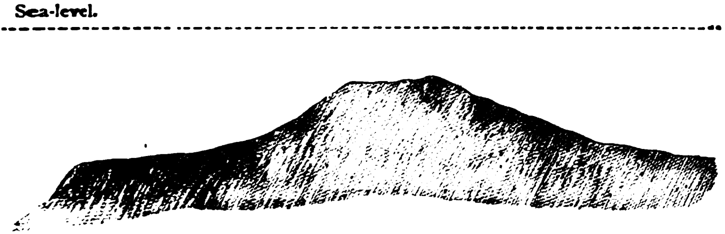


FIG. 85.—First stage. A submarine mountain.

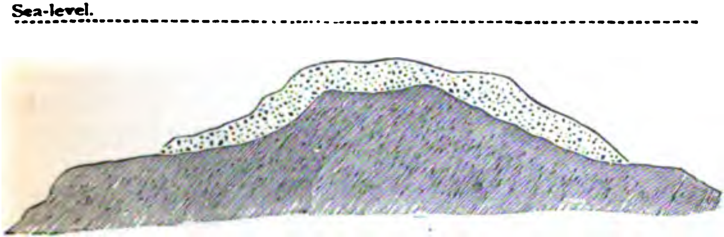


FIG. 86.—Second stage. The submarine mountain raised in height by the accumulation on it of minute shells, etc.

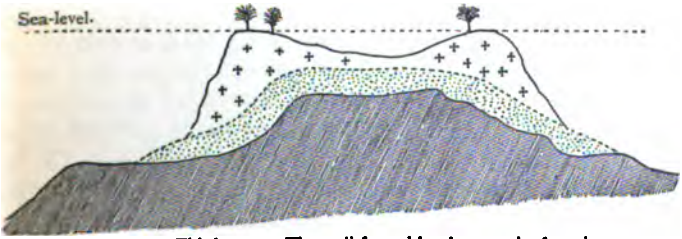


FIG. 87.—Third stage. The atoll formed by the growth of coral.

Another theory, however, has been brought forward by

Mr. John Murray, one of the naturalists of the *Challenger* expedition, which dispenses with the necessity of supposing that the bottom of the ocean has moved at all. This theory is briefly as follows: Submarine volcanic mountains, that is, volcanoes which have been formed by eruptions which have never reached the surface of the water, are very common in the oceans. Many of these rise to within a few hundred feet of the surface. The upper waters of the ocean swarm with animal life, many of the organisms being protected by delicate shells, which, when they die, sink slowly to the bottom. If they have far to go the more delicate ones get dissolved before the bottom is reached, owing to the carbonic acid which is always present in the sea-water. If, however, the sea is shallow in any part, as it would be over a submarine mountain, they accumulate at the bottom, and gradually the pile approaches the surface near enough to allow corals to grow upon it. These gradually raise their reef to the surface. As they can get little food on the inside, they grow outwards, and keep a space of open water in the centre, and so form an atoll. In this way an atoll may be formed without any previously existing island. Figs. 85–87 illustrate this theory.

Each of these theories has its strong and weak points. Some areas which, according to Darwin, ought to be rising are really sinking. Murray's theory requires the curious coincidence of an extraordinary number of submarine volcanoes rising very near to the surface.

Along some parts of the coast in England, as well as in other countries, there are, below low-water mark, and only visible at exceptionally low tides, the stumps and roots of trees still firmly embedded in the ground, evidently portions of a submerged forest upon which the sea encroached. This proves recent submergence. Going further back we find beds of coal, which are ancient submerged forests, now lying buried in the rocks far below the sea-level, some coal mines in the North of England actually extending under the sea.

There is very little doubt that the inlets, called "fiords" in Norway and "firths" in Scotland, are submerged valleys or ravines, which were originally cut out by either streams or glaciers, or both. The sea fills them up for a long distance, but they extend still farther inland above the level of the sea, and they still have streams running down them. Part of the valley is, in fact, above the sea, and part below it. The sea obviously could not cut out the part above, so that we may infer that it did not cut out the part which it now fills. Moreover, the sea is very deep in these inlets, and we have already seen that the sea has little or no denuding power a few yards below the surface. These submerged valleys are then also a proof of change of level. In the south of Sweden and on the coast of Greenland, streets, landing-places, etc., formerly in use are now below the sea. Portions of the old town of Kingston in Jamaica are beneath the sea. The inroads of the sea in Holland are due to the gradual sinking of the land below the sea-level. Near Naples there are some ruins of a Roman bathing establishment, commonly, but wrongly, called the "Temple of Serapis." The place was certainly not built under water, and it is not under water at present; yet, nevertheless, some of the tall pillars which are still standing in position are perforated by boring molluscs, which can only live in the sea, many of the holes still containing the shells of the creatures which bored them, and these holes are found to a height of twenty feet above the base of the pillars. This seems to indicate that the ground has sunk down and been again elevated. This last case is near Vesuvius, and in the midst of a volcanic neighbourhood, and it has been observed that indications of change of level are more frequent in such localities.

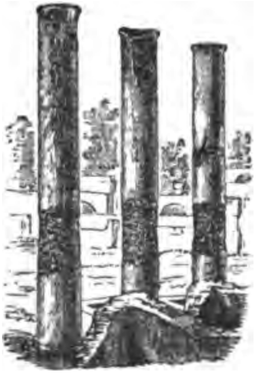


FIG. 88.—The perforated columns of the "Temple of Serapis."

There is no doubt, therefore, that there is some force at work lifting up the earth's crust in one place and letting it down at another. It is not the level of the sea which is rising and falling. If it were, it would affect the whole coast alike, and this is not the case. The risings and fallings are confined often to small areas. But we not only find the stratified rocks lifted high above the ocean in which they are formed; they are tilted up at every possible angle, and sometimes quite overturned; they are broken and crushed and contorted; in some cases, especially where most crushed and bent, they are altered almost or quite beyond recognition. In seeking for a cause of the elevation, we must, if possible, also find one which will offer a reasonable explanation of these other facts.

Although the outside of the earth seems to derive all its heat from the sun, and to be hot or cold according as the sun shines on it much or little, yet there appears to be a great body of heat in the interior of the earth which is not derived from the sun. In mines, after a certain depth is reached, the heat invariably increases with the depth, at a rate, on the average, of about 1° Fahr. for every sixty feet; so that at the depth of a mile the temperature would be at least 100° Fahr. Hot springs are common nearly all over the world; and wherever a deep boring is made for water, the water is always warm in proportion to the depth from which it comes. Volcanoes, which pour out white-hot molten lava, also prove the same fact. As hot springs, mines, and volcanoes all over the world bear this testimony, it is evidently not a case of heat at one or two limited localities, but of heat throughout the whole of the earth's interior. We cannot say how far the rule of increase of temperature holds; but we may assume that the heat continues to increase, at least, for some distance further, and there is every probability that at a depth of a few miles it exceeds any temperature with which we are acquainted. The next question which arises is as to whether the earth is molten at this comparatively small depth: whether, in fact, the earth is a great globe of intensely hot molten matter, with a crust over it only a few miles thick; or whether it is solid wholly or partly. Astronomers tell us that it is certainly not almost entirely liquid, because, if it were, the attraction of the moon and sun would cause tides in the internal fluid just as they do in the ocean, and that the internal tides would cause the thin crust to rise and fall twice a day, which it certainly does not. They conclude, therefore, that the solid crust must be at least several hundred miles thick. Accepting this statement, then, we may say that the earth is either entirely solid, or has a very thick solid crust and a centre wholly or partly molten. It does not, however, follow from this that the heat is any the less. Most of the materials of which the earth is made expand and take up more room when they melt, and it is possible that the pressure of the outside rocks is so great as to prevent them expanding, and consequently also prevents them from melting. Astronomers tell us that the weight of the earth is considerably greater than it would be if composed of ordinary stone, unless it were compressed into something like half its bulk; and it is thought that in the interior there may be more metallic material, such as iron, etc., than there is in the rocks near the surface.

We have, then, at any rate, this important fact, that the earth is much hotter in the interior than in the outside crust, and that down to a great depth it is, at any rate for the most part, solid. The next question is, is it getting hotter or colder? We know of no means by which a ball like the earth, cool on the outside, could go on getting hotter from the interior; and, going again to the astronomers for information, we learn that there are many reasons for believing that the planets, including the earth, were once so intensely hot that they existed merely as great masses of gas or vapour. These globes of vapour are supposed to have slowly cooled, and finally to have condensed into liquid, just in the same way as steam condenses into water, or as aqueous vapour in the air condenses into raindrops. The globes of molten material, still cooling, finally became solid and cold on the outside, while the inside still remained liquid; and this process has brought the earth into its present state. This is what is called the "nebular hypothesis" of the earth. We are by no means absolutely sure that it is true, but it seems to explain the present condition of the earth, and other heavenly bodies as well, in a more satisfactory way than any other theory. We conclude, then, that the earth has been for a long period, and still is, getting cooler and cooler. Now, just as increase of heat causes bodies to expand, so decrease of heat causes them to contract; and the hotter they are, the greater the rate at which they contract as they cool. Consequently the interior portion of the earth will, as it cools, contract at a greater rate than the crust. The consequence will be that a hollow space will be formed, and the crust will either form an arch over it, or crush down upon it. If a portion of the outside of a globe crushes in nearer the centre it will have less room to spread in, and will consequently be crushed up laterally.

Suppose in Fig. 89 the section A C D B to sink down into the position C E F D, being crushed down into that position by its own weight. As A B is greater than C D, and C D than E F, it is clear that it will have to get shorter.

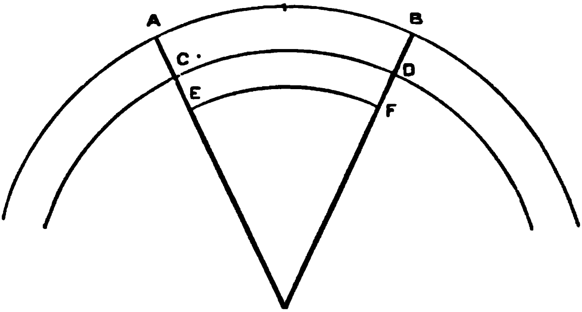


FIG. 89.

We can form an idea of what will happen by the following experiment. Place a pile of neatly packed pieces of cloth between two boards, put a half-hundred weight on the top, and compel the pile to get shorter by forces applied in the direction of the arrows. The cloth is compelled to go into wrinkles, and so, no doubt, would the strata A C D B, Fig. 89. In the experiment the half-hundredweight represents the weight of the upper layers of rock in the crust. The cloth will not go into a number of complicated folds unless it is pressed from above. If the weight is replaced by a great pile of cloth, and lateral pressure applied, the contortions of the lower beds will gradually fade away upwards into one long gentle upward bend. From this we conclude that highly contorted strata were acted upon deep down in the earth, and have been since exposed by denudation. It is also obvious that, although the average result is a lowering of the surface, yet it is accompanied by elevation. The process of the crust sinking and settling down on a contracting nucleus may be illustrated by the case of a withered apple. The apple dries and get smaller, and the skin adapts itself to it by wrinkling. This theory of the contracting nucleus seems to explain in a satisfactory manner the rising and sinking of the land, as well as the tilting, breaking, and contorting of the strata. There remains the question as of whether it will explain the metamorphism of the strata.

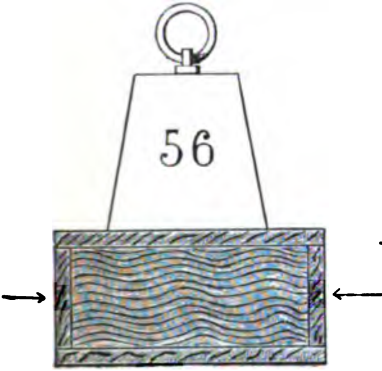


FIG. 90.

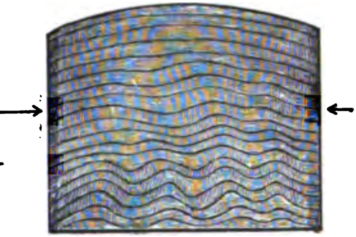


FIG. 91.

One of the most important scientific discoveries of recent times is that all the various manifestations of energy are capable of conversion into each other. For example, energy in the form of heat can be converted into mechanical energy, as is the case in the steam-engine; and mechanical energy can be converted into electrical energy, as is done in electric-light machinery; or it can be turned back into heat again. As an illustration of the conversion of mechanical energy into heat, we have the fact that if a piece of cold iron is placed on an anvil, and struck with a heavy hammer, it becomes hot; the mechanical energy of the moving hammer disappears, and at the same time heat is developed. There is, moreover, a direct relation between the amount of heat which manifests itself and the mechanical energy which disappears. The heat is produced in the iron by its sudden compression; and in the same manner, it is believed, that when a great mass of strata sinks down by its own weight, the lateral pressure which throws it into folds also develops a very large amount of heat. Now, this heat, acting in conjunction with the great pressure and the water with which nearly all rocks are more or less saturated, probably brings about those changes in the rocks which we call *metamorphism.* Geology is not a science which is easily illustrated by experiment, and we cannot expect to be ever able to convert ordinary aqueous rocks to schists and other forms, but it is, nevertheless, possible to clear up a few difficulties by experiment. For instance, slate, as has been already explained, possesses a structure known as "cleavage," a tendency to split into thin layers in a direction which may be, but generally is not, the direction of the bedding. Light has been thrown on this peculiarity by submitting a mass of clay to intense pressure while shut up in a strong box. In whatever direction the pressure was applied, it was always found that the clay had developed a tendency to split into layers at right angles to that direction. A block of limestone was closely shut up so as to prevent the escape of carbonic acid, and then kept at a white heat for some time. After cooling, it was found to be converted into a kind of marble. A block of sandstone similarly treated was found to be much harder and more difficult to break, owing to the grains having been apparently fused together, forming a stone very like quartzite. Other and more complex mineral changes have also been produced by submitting rocks to very high temperatures. There are also cases where various fresh minerals have been formed by the long-continued action of hot springs upon brickwork. Wherever granite, basalt, or other igneous rocks have

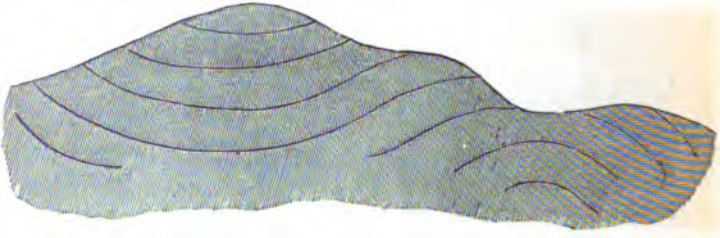


FIG. 92.—The thin parallel lines represent cleavage planes; the curved lines are the lines of bedding.

burst through or into the stratified rocks, it almost invariably happens that those parts which touch or are near the eruptive rocks are altered in texture and appearance—limestone into marble, sandstone into quartzite, shale into hard splintery rock, and sometimes various kinds of schists are found. There cannot be any doubt that these changes have been caused by the heat from the intruding rock. There is thus plenty of evidence that pressure, heat, and water, either separately or combined, will produce great changes in rocks. But in the schists we have thin separate layers of such mineral matters as quartz, talc, hornblende, mica, felspar, etc. Can these have got into this condition by the aid of the above agencies? When water is heated under ordinary conditions it will not rise to a higher temperature than 212° Fahr., which is the boiling-point. Any further heat which is put into it employs itself, not in making it hotter, but in converting it into steam. But if the water is shut up under pressure, and prevented from turning into steam, it will get hotter and hotter; and the hotter it gets, the greater is its power of dissolving various substances. We can well conceive, therefore, that under the intense heat which would be generated by the crushing and folding of the rocks many chemical changes would take place which would never occur at the surface. Various mineral substances would be dissolved in the percolating water, and would, by their action on each other, produce fresh minerals; and these minerals, under the influence of the pressure, would tend to deposit themselves in layers, and produce the foliated or schistose structure which characterizes many of the metamorphic rocks. If this theory is correct, we can, of course, conceive it possible for granite, basalt, and other igneous rocks to be converted into schists as well as aqueous rocks.

If this is the true theory of metamorphism, we shall find the most intensely altered rocks in those regions—namely, the great mountain chains—where the crumpling is greatest, and this is exactly the case. If cleavage is produced by lateral pressure, then the planes of cleavage will run parallel to the axes of the anticlinal and synclinal curves. This is also the case. If the contortions and the metamorphism were produced deep down in the crust, we should find ample evidence of extensive denundation wherever contorted and metamorphic rocks are visible at the surface. This is invariably the case. Fig. 93 will give a general idea of the arrangement of the rocks in a section across a range of mountains, and will illustrate the extent to which the contortion is sometimes carried.

There is one other point. The heat may be great enough to actually melt some of the rocks in the lower portion. In this case they will, as they solidify, put on all the appearance of igneous rocks, which, indeed, they will be. It is therefore conceivable that the same bed may in the deeper portions of its curves consist of igneous rocks, in the middle of metamorphic, and in the upper may be altered only slightly, or even not at all.

In some mountain ranges the contortion and metamorphism have not been so great; in some, indeed, there is contortion in a less extreme form without metamorphism at all. Such is, for instance, the case in the Jura (Fig. 94).

Metamorphic agents, acting deep down in the earth, often affect wide areas, which, when exposed by denudation, present to our view regions like the Scotch Highlands. Here we have some sixteen thousand square miles of country occupied by gneiss and crystalline schists, contorted, faulted, inverted, and thrust among and over each other in endless and almost inextricable confusion, and probably extending a long distance underground, where they are covered by more recent strata.

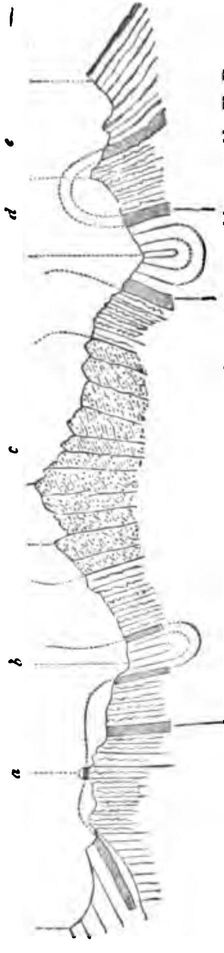


FIG. 93.—Effect of intense lateral pressure, causing contortion, inversion, and metamorphism. *a*, Aiguille Rouge; *b*, Chamouni; *c*, M. Blanc (observe the *fan structure*); *d*, Val Veni; *e*, M. Chetif; *f*, Cramont.

Metamorphism such as this is, no doubt, brought about by the means above described, and, as it generally affects wide areas, it is called "regional metamorphism." But in some cases a more local metamorphism is caused by the squeezing or thrusting up into stratified rocks of granite and other igneous rocks. These thrusts are, no doubt, due to the same cause as the crushing and bending and heating which produce ordinary metamorphism, viz. shrinkage. An ordinary volcanic dyke can be generally seen to have baked and altered more or less the strata through which it passes; but large intrusive masses of granite have a more marked and extensive effect. Numerous cases have been described. Near Christiana a granitic boss has intruded among fossiliferous rocks, and has altered them for a distance of some hundreds of yards. The shales have become hard and jaspery, and crystals of hornblende, felspar, and mica have been developed in them, while the stratification has been obscured and the fossils obliterated. An earthy coralline limestone is changed near the granite into a white granular marble. The Dartmoor granite has had a somewhat similar effect, and many other cases could be produced. Such action, however, is obviously very different to that which has brought about the metamorphism of thousands of square miles of strata.

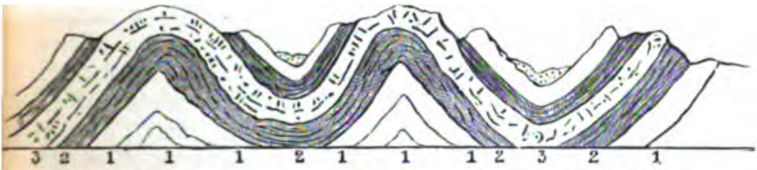


FIG. 94.—Section to illustrate structure of the Jura. Contortion without inversion or metamorphism. 1, Trias; 2, Lias; 3, Oolite.

A general account of the structure and phenomena of *Volcanoes* has been given under the head of "igneous rocks." From the description there given it is clear that a volcano is not a "burning mountain," as some geography-books call it, inasmuch as it never burns, and it is not necessarily a mountain. Some volcanoes, like Stromboli, are in a state of almost perpetual activity; some, like Vesuvius, are only periodically active; while others, like the mountains of Auvergne, in France, quite or nearly perfect, with their craters and lava-fields, have never been in eruption within historical times. The latter are called *extinct* volcanoes, but the distinction is not of much value, because such volcanoes not unfrequently burst into full activity all of a sudden. Vesuvius did so when, in A.D. 79, it buried Pompeii and Herculaneum in its dust. Some volcanoes, although they do not seem to have sufficient energy left to hurl their products high into the air, or to bring up lava, throw out large quantities of mud produced by the admixture of the condensed steam and volcanic dust (*mud volcanoes*), or they merely give vent to various gases mingled with steam (*fumeroles* and *solfataras*). *Geysers*, or natural fountains of hot water, are also thought to be due to expiring volcanic energy. Like all other parts of the earth's surface, volcanoes are subject to denundation, and they may be found in all stages of ruin and decay. A volcanic cone often gets "breached," or broken away on one side; but if it does not, the crater frequently fills with water, and forms a clear lake. Many of these craters may be seen in Italy. One of them, the Alban Lake, a few miles from Rome, was utilized in ancient times by tapping it, by means of a tunnel through the

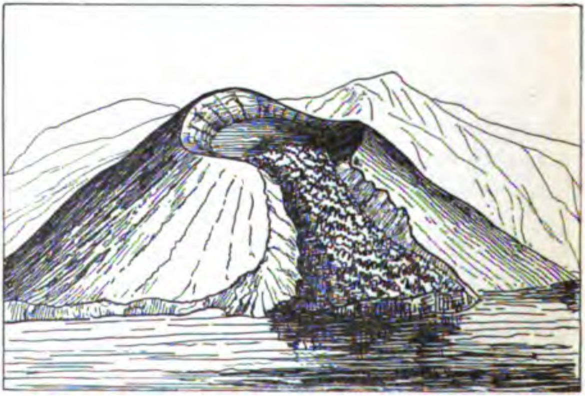


FIG. 95.—A "breached" cone.

lip of the crater, and conveying its water to the city by means of aqueducts over the intervening plain. On the other hand, there are volcanoes which can only be traced by the presence of the stump of the hard plug of lava which has solidified in their craters, and by vestiges of their lavas here and there; and in some cases the lava is seen, but the volcano from which it came has entirely disappeared. Such is the case, for instance, with the great volcano which ejected the lava of Staffa and the Giant's Causeway. Volcanoes appear to have existed at all periods, as we find their products, in the shape of lava and beds of ashes, inter-stratified with and overlaid by the very oldest aqueous rocks.

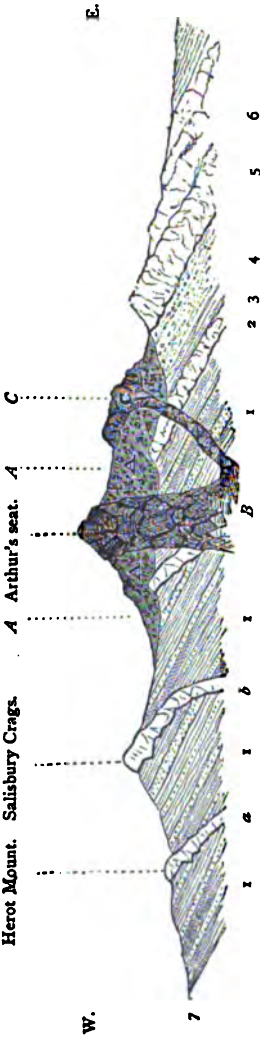


FIG. 96.—Section across Arthur's Seat. 1, Stratified aqueous rocks; 2, Dolerite; 3, Limestone: 4, Volcanic tuff; 5, Lavas; 6, Sandstone, etc. *a*, *b*, Intrusive dolerite. *A*, *B*, *C*, Later volcanic rocks.

Closely connected with volcanoes are *Earthquakes*. Earthquakes manifest themselves by sudden tremblings and shakings of the earth, often violent enough to overthrow buildings, and even whole towns, if they are so unfortunate as to be near the locality of the disturbance. They also, sometimes, cause a permanent elevation or depression of the ground. The phenomena of volcanoes and earthquakes are perhaps the most terrible and awe-inspiring of all natural occurrences, and there have been many speculations as to their cause. They are more frequent near the sea than far from it, and they are common among many of the great mountain ranges of the world. It is therefore thought that most probably they are caused by the action of the intense heat produced in the manner explained above. The rocks are saturated with water, and, when sufficiently heated, even under great pressure, it turns into steam with explosive violence, causing earthquakes, and, when it forces a vent, forming a volcano. This theory is strengthened by the fact that steam is always very abundant in volcanic eruptions, especially during the early stages, and the lava is always full of steam, which rises from it in a dense cloud as it flows down the side of the volcano. Moreover, a volcanic eruption is generally preceded by shakings of the earth, which cease as soon as the rush of steam from the crater occurs. It used to be thought that the molten lava was derived from the hot molten interior of the earth; but from what has been said about the thickness of the solid crust, this explanation will be seen to be impossible.

SUMMARY.—1. All the agencies hitherto considered tend to wear the dry land away, and still it exists. There must, therefore, be some counteracting force.

2. This force is that which causes movements of the earth's crust, of which we become aware from the fact that—

- (*a*) aqueous rocks are now found high above the sea;
- (*b*) raised beaches and old lines of cliff fringe the land margins;
- (*c*) some islands consist of coral, and stand high out of the water;
- (*d*) there are cases of submerged forests, quays, and buildings.

3. It is the land which rises and falls, not the sea.

4. That the earth's interior is hot is proved by observation of—

- (*a*) mines;
- (*b*) volcanoes;
- (*c*) hot springs.

5. But though hot, the earth is probably not to a large extent molten, and it is still cooling. In cooling it contracts, and the outer crust in settling down gets broken, crushed, and contorted.

6. The lateral squeezing generates additional heat; and

this, in conjunction with the water of saturation, induces *regional metamorphism.*

7. Other rocks become locally metamorphosed by *contact* with intrusive igneous rocks.

8. *Volcanoes* are manifestations of the internal heat. They have existed at all times, and may be found in every stage of decay. Some have breached craters, while some contain lakes. Others can only be traced by their products.

9. *Earthquakes* are also connected with the subterranean heat, and are probably caused by sudden generation of steam.

QUESTIONS.

1. Give proofs of the instability and oscillations of the earth's crust.
2. What is taught us by the "Temple of Serapis"?
3. What proofs are there that the earth is intensely heated a short distance down, and that, though heated, it is not molten?
4. What causes the sinkings and risings of the earth's crust?
5. How many kinds of metamorphism are there? Describe each, with examples.
6. Describe and explain the phenomena of volcanoes and earthquakes.
7. In what condition do volcanoes now exist, and how do we know that there were volcanoes in very ancient times?

CHAPTER XV.

SUBSEQUENT CHANGES IN ROCKS.

In a previous chapter we have seen how the various kinds of stratified rocks are laid down along the seashore, at river-mouths, in the deep sea, or in lakes; and we have seen that, as far as composition goes, there is no essential difference between those which we see in process of formation now and those which were formed long ago and now constitute a large portion of the solid earth. But there are, nevertheless, important differences. The older rocks have many of them been elevated far above the level at which they were formed. Instead of being loose and incoherent, they are in many cases extremely hard; and instead of lying in horizontal, unbroken layers, they are often inclined, bent, cracked, and displaced in various ways.

The hardening process begins soon after a deposit is formed. The pressure of overlying material squeezes the particles closer together, forces out a portion of the water, and causes a certain amount of consolidation; and in the cases of some beds of clay and sand, even of considerable antiquity, this is all that has taken place. Generally, however, various substances, such as carbonate of lime, oxide of iron, or silica, are chemically deposited by percolating water among the particles, and cement them together into a solid mass. In the case of an accumulation of coral or shells, the water which filters slowly through it dissolves here and deposits there, and so gradually converts the whole into a compact mass of limestone. In some instances, when the deposit is very deeply buried, it is influenced by the subterranean heat, and subjected to a process of baking in addition. Thus, under the action of pressure, infiltration, and heat, soft aqueous deposits are converted into hard rocks. No definite line can be drawn between this hardening action and metamorphism, though the latter term is restricted to those extensive structural and chemical changes which practically result in the production of another kind of rock, possessing characters which were entirely absent in it originally.

All the rocks which are hardened as above described are traversed by cracks or *joints*, nearly or quite perpendicular to the bedding. There are generally two sets, all the joints of one set being parallel to each other, and approximately at right angles to those of the other set. These joints often pass through several layers of rock, and, in combination with the bedding, they divide the rock into rectangular slabs, and are thus of great assistance to the quarrymen. Those joints which are of greater extent than the others are called *master joints*. The best illustrations of jointing may be seen in massive sandstones and limestones; but igneous rocks are also jointed, generally by three sets oblique to each other. The prismatic columns of basalt are obviously due to such triple jointing. Several causes of this jointed structure have been suggested. In the case of aqueous rocks it is certainly not an attempt at crystallization, as these rocks are mechanical mixtures of various substances, and crystallization only takes place in the case of chemical compounds. For example, in the case of a ferruginous sandstone there could be no crystalline force acting on a mass of particles of silica cemented together with oxide of iron, though both the silica and the iron oxide will form crystals themselves. There is a peculiar sandstone at Fontainebleau which can be broken into rhombohedrons, but this is really caused by the presence of a very large amount of calcite, which has crystallized in spite of the presence of the admixture of sand. Jointed rocks, moreover, whether aqueous or igneous, show no tendency to that cleavage which is very characteristic of crystalline structure. No doubt in some cases the joints are cracks caused by shrinkage as the soft aqueous rocks consolidate and harden, or as the liquid igneous rocks solidify; but this will not explain all the facts. For instance, it has been noticed that, when a rock slopes in any particular direction, there are well-developed joints running across at right angles to the direction of the slope and others down the line of slope; and it has also been observed that, in the case of coarse conglomeratic rocks, the embedded pebbles are often split clean across if they come in the line of a joint. Both these facts suggest that the joints are due to the action of a strain acting on the stratum of rock when it is being elevated, tilted, or bent; and this, no doubt, is the main cause of jointing.

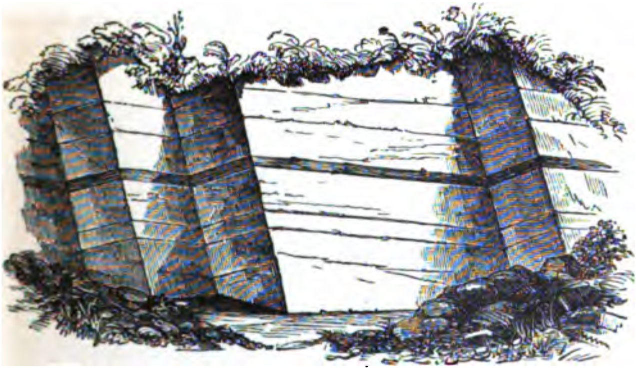


FIG. 97.—Quarry in jointed rock.

The displacement of rocks from their original horizontal position appeals to the most superficial observer. When a slab of clayey sandstone standing nearly vertical bears on its surface ripple-marks, sun-cracks, footprints, etc., it is obvious that it cannot be in the position in which it was when the marks were made. Sometimes roots of trees, with a part of the trunk attached, are found fossilized, and these trunks are always found to be nearly or quite at right angles to the line of bedding, whether it is now horizontal, inclined, or vertical. Tree trunks, however, always grow vertically upright, so that if these fossil trunks are not upright now it must be because the strata containing them have been shifted. If a portion of the upper surface of a bed of rock is laid bare in a quarry, it may possibly be found to be perfectly horizontal; but, as a rule, it will have a slope, large or small, in some particular direction. If a small quantity of water is poured on it, the water will run off downhill in the direction of the slope. This direction is called the *dip*, and is indicated by naming the point of the compass towards which the downward slope is directed. Thus, if we say that a rock has a south-east dip, we mean that the bed slopes downwards towards the south-east, that water or a marble placed upon it would move in that

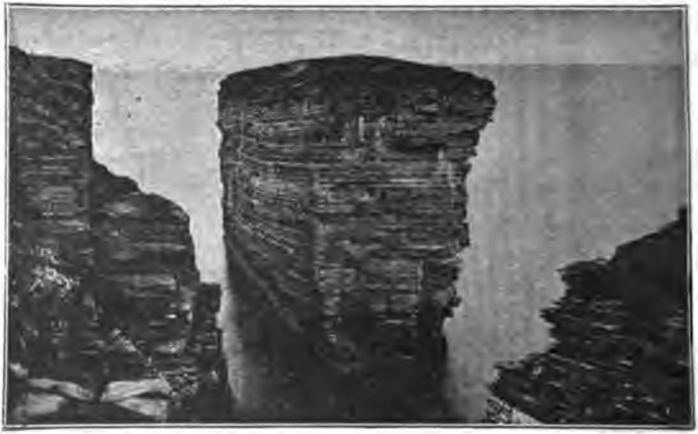


FIG. 98.—The "Clett" Rock, Holborn Head, Thurso. (Wilson.) Observe the effect of the joints at right angles to each other.

direction. The amount of the dip is given by stating the number of degrees contained in the angle which the dip-slope makes with a horizontal line, thus, 15° S.E. A horizontal line at right angles to the dip is called the *strike.* If the dip is the same throughout a district, and the surface of the ground perfectly flat, then the strike corresponds with, or is parallel to, the line along which any particular stratum appears at the surface. This latter line is called the *outcrop.* It is the line where the rock "crops out" or rises to the surface. Dip, strike, and outcrop are three very important things to determine in studying the geology of a district, and are not always very easy to ascertain. For example, the dip is easily settled when a bare, clean surface of rock of sufficient extent can be obtained as described above, but in practice this is rarely the case. A little consideration will show that the edges of inclined strata may look perfectly horizontal when seen on the face of a quarry, and that even when they can be seen to be inclined it is impossible to determine either the amount or the direction of the dip from the examination of the one face only. When two faces can be examined, the direction and amount of the dip can be calculated. The dip being determined, the strike is easy; but it must be remembered that strike is not any particular line, but merely direction. The line of outcrop is often very complex. It depends on the dip of the beds and on the contour of the ground conjointly. When the beds are perfectly horizontal, and the surface is carved out into hills and valleys, the outcrops of the different strata are always found when a certain elevation is reached, so that the

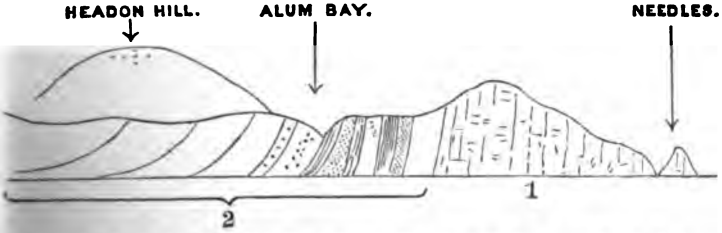


FIG. 99.—Vertical and highly inclined strata in the Isle of Wight. 2, sands; 1, chalk.

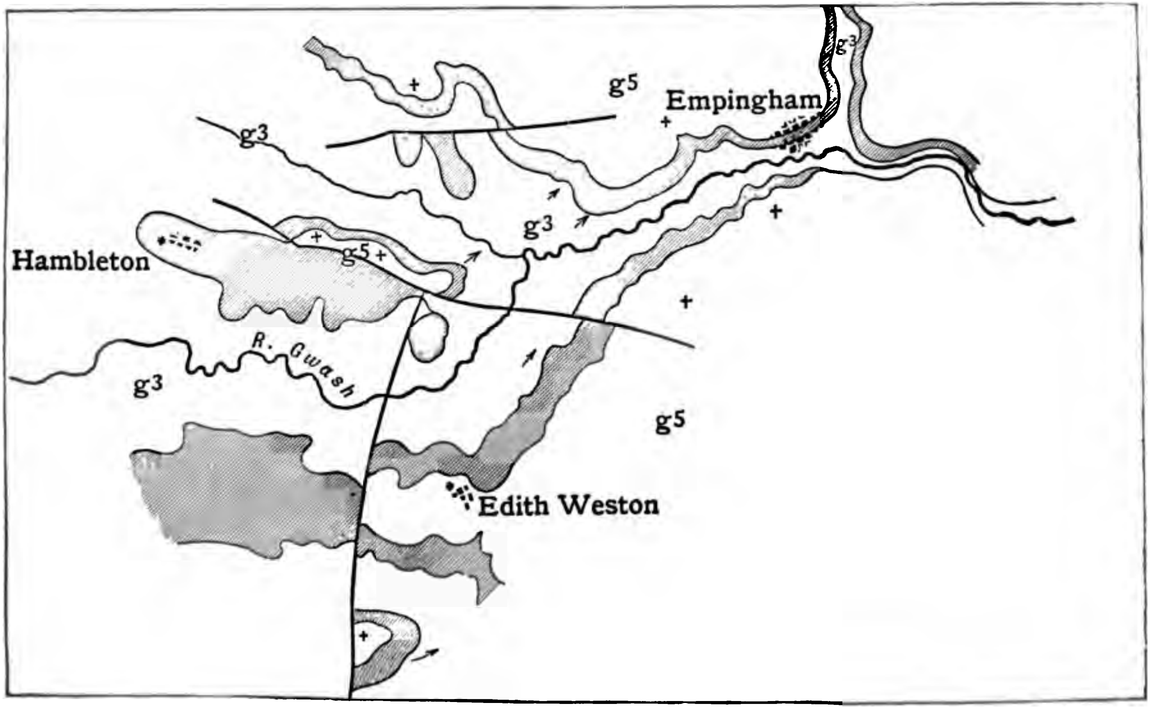


FIG. 100.—Map of the Gwash Valley, Rutlandshire, to illustrate outcrop. *g*3, Upper Lias clay; *g*5, Lincolnshire oolite; shaded portion Northampton sand, lying above *g*3 and below *g*5.

lines of outcrop correspond with the contour lines. It is rarely that this is perfectly the case, but something approximating to it may be seen among the Yorkshire dales, where the outcrops of the beds of mountain limestone, Yoredale rocks, and Millstone grit are met with as one ascends higher and higher from the bottom of the dales to the hill-tops. As one walks up one of these dales the outcrop of some easily recognized bed may be seen, at first high up, on both sides of the valley. The further one walks the lower the outcrop seems to come, till at last it is level with the bottom of the dale; then it crosses and joins that on the other side, perhaps causing a small waterfall in the stream which is always present in these dales. Each outcrop in this way forms a V-shaped curve with the base of the V pointing up the dale. From the consideration of this simple case of horizontal beds it is not difficult to pass to that of inclined beds. Suppose the beds, instead of being horizontal, to have a slight dip towards the head of the dale, the V will then become blunter. If the dip is now imagined to gradually get greater and greater, still in the same direction, the V will more and more approximate to a straight line, until when the strata, instead of being horizontal, are vertical, the outcrop will run straight across the valley. Returning now to the horizontal stratum, let up suppose that it is gradually tilted so as to dip down the valley instead of up it. It is evident that this will elongate the V. When the dip of the beds exactly coincides with the slope of the valley it is clear that no V will be formed, but that the outcrops of the different beds will be found preserving the same distance from the bottom of the valley all the way up, and never descending to the stream at all, and that the stream will be flowing over the same stratum all the way. Such a state of things is very unlikely to occur, as most valleys get steeper and steeper the further we go up them, and it would be very unusual to find the inclination of the strata exactly keeping pace with this increasing slope for a very long distance. When the dip is greater than the valley slope, the outcrop then forms a V with its base pointing down the valley, the V becoming blunter and blunter as the dip is greater, until, when the strata are vertical, it cuts straight across the valley as before. The width of the outcrop depends on the thickness of the bed, the dip, and the shape of the ground. It cannot be *less* than the total thickness of the bed, but there is no limit in the other direction. A nearly or quite horizontal stratum, even if thin, in a comparatively level country, may have an outcrop miles in width. These considerations serve to explain the apparently irregular arrangement of the colours in a geological map.

If we find the strata dipping one way at one place and another way at another, it is clear that there is a bend somewhere. When the dip is away from a certain line in two opposite directions, and the bent strata form a ridge, it is called an *anticlinal*, or *saddle;* when the dip is towards a line, so as to form a *trough*, it is called a *synclinal.* These ridges and troughs, however, very rarely show as such at the surface, owing to denudation. Sometimes the strata dip in all directions away from a certain point; the dip is then said to be *quaquaversal*, and the structure is called a **dome.** The opposite state of things, when the dip all round is towards a point, is called a *basin.* In these cases, again, the surface of the ground may be any shape. A line through those parts of a bed in an anticlinal or synclinal where the dip is neither way is called the *axis;* the plane containing the axes of a series of curved beds lying one below the other, is called the *axis-plane.* When the dip is the same on both sides of the axis—that is, when the anticlinal or synclinal is quite symmetrical—the axis-plane is vertical; but when the dip is greater on one side than the other, the axis-plane is inclined. A good example of an anti-

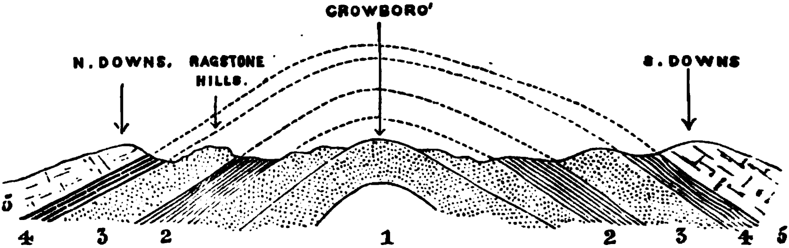


FIG. 101.—The Wealden Anticlinal. Section from the English Channel to the Thames. 1, Hastings beds; 2, Weald clay; 3, lower greensand; 4, gault and upper greensand; 5, chalk.

clinal on a large scale may be seen in the strata between London and Brighton, where the chalk and a series of beds below it have been bent into an enormous saddle, the top of which has been cut off, and the lower beds exposed in the middle. At Spithead, on the other hand, the chalk is deeply buried, and covered with other strata, and rises to the surface on the north in Hampshire, and on the south in the centre of the Isle of Wight, forming a synclinal, or trough, with an eastern and western axis. In the case of gentle undulations the dip is generally the same on both sides; but where there has been much disturbance this is often not the case, and sometimes the strata on one side are bent underneath those which were originally below them, so as to produce a very deceptive appearance in a section. This is called *inversion.*

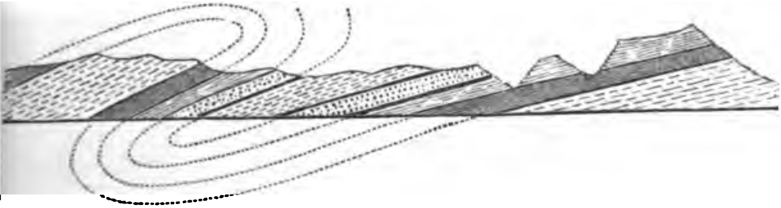


FIG. 102.—A case of contorted and inverted strata in the Jura. The strata can be followed by the help of dotted lines.

The hills of North-west Yorkshire were quoted above as an illustration of the outcrops of horizontal rocks corresponding with the contours. The hills stand on a base of carboniferous limestone, which rises some way up their sides. Higher up are the shales and limestones known as the Yoredale rocks; and above them, forming a cap on the top of each, is the millstone grit. These cappings of millstone grit were once undoubtedly

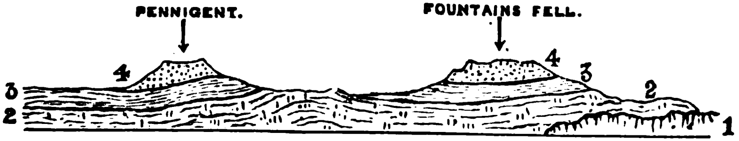


FIG. 103.—Strata, nearly horizontal, carved into hill and valleys. 1, Silurian strata; 2, mountain limestone; 3, Yoredale rocks; 4, millstone grit. West Riding of Yorkshire.

continuous, as were also the Yoredales below them, but long-continued denudation has isolated them from each other by cutting deep valleys round the hills. Such isolated patches of rock are called *outliers.* They may be defined as masses of rock resting on the surface, and surrounded on all sides by older strata. Such outliers are fragments of strata which were once more extensive, and they are often the only remaining evidence that a formation once extended over strata from which they have since been removed. Thus the chalk hills which form the line of the North Downs present, as a rule, a surface of chalk clothed with a thin clayey soil, with nothing to indicate that more recent strata have ever rested on it; but here and there a slight tree-clad eminence is found to consist of sands belonging to the Tertiary system, which is only found in any force some miles to the northward. The isolated patch of sand, however, tells us that Tertiary strata once spread over the whole surface of the chalk. Such outliers are very common. Outliers do not, however, always rise above the level of the surrounding country. Frequently they are found in troughs and basins where the surface of the ground is quite flat.

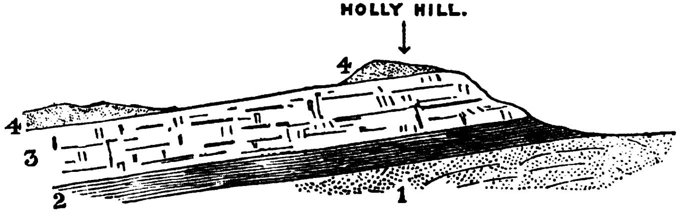


FIG. 104.—An outlier consisting of beds of tertiary sand and pebbles (4) lying on beds of chalk (3). Holly Hill, near Rochester.

When strata are in any way removed so as to expose a portion of a bed lying below them in such a way that the exposed portion is surrounded on all sides by the higher strata, an *inlier* is formed. If a hollow were to be scooped out of horizontal strata, or the top sliced off a dome, so as to expose strata which were before hidden from view, inliers would be formed. The most common form of inlier is that which is made by a river cutting out a valley in strata which dip in the same direction as the river is flowing. An inlier, therefore, is a portion of a stratum which is continuous underground. Several inliers of the same rock in the same neighbourhood may be, therefore, portions of one continuous unbroken stratum. Outliers, on the other hand, are mere vestiges of what was once similarly continuous.

The strain on the rocks which produces the cracks, joints, and contortions frequently fractures the strata through a considerable depth, and produces a dislocation, or *fault*. When this happens the strata on one side of the crack slip down to a lower position, often crushing, bending, and grinding the broken edges of the strata against each other, and producing great confusion. Very often a fault is associated with several other smaller ones, which are nearly or quite parallel to it. Faults cause

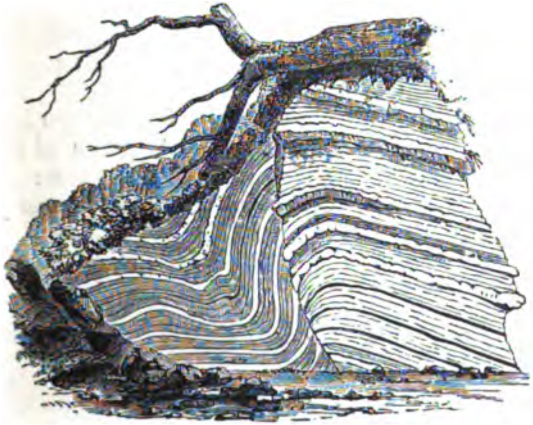


FIG. 105.—Contorted beds in the neighbourhood of a fault.

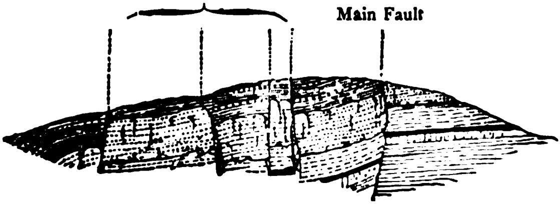


FIG. 106.—Faults.

considerable trouble to miners, inasmuch as, when the surface of the fault is reached, the stratum of coal, ironstone, etc., stops short, and has to be sought for higher up or lower down. Faults are generally more or less slanting, and almost invariably the strata which are thrown down are those towards which the fault slopes, or *hades.* When the other side is let down it is said to be a *reversed fault.* The perpendicular distance between the two portions of any dislocated stratum is called the *downthrow*, or *throw.* The downthrow varies from a few inches to thousands of feet. As an instance of a very large downthrow the Pennine Fault may be mentioned, where the carboniferous limestone hills overlook, in the vale of Eden some two thousand feet below, Permian strata of more recent age than themselves, which have been thrown down by a great fault running nearly north and south. A branch of this fault running eastward to the south of Ingleborough has thrown down in the same way some coal-bearing strata whose natural position

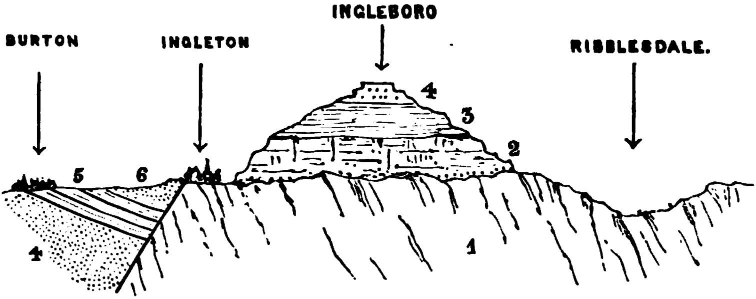


FIG. 107.—The Craven Fault, a branch of the Pennine. Here the downthrow is at least 2000 feet. The bed No. 4, called the Millstone Grit, which forms the summit of Ingleboro Hill, is thrown down far below the surface between Burton and Ingleton.

would be above the millstone grit which caps the hill. Outliers and inliers are in many cases bounded on one or even two sides by faults, and it will be readily understood that lines of outcrop are seriously disturbed when they are intersected by faults, although without models it is not easy to make the exact manner of this quite clear. The intense friction of the dislocated strata as one grinds over the other often produces on one or both faces a scratched and polished appearance not unlike glacial markings (*slickenside*), and also causes the strata in juxtaposition to bend, those on the downthrow side upwards, and the others downwards. In other cases the fracture is filled with crushed and broken material, among which crystalline and mineral matter has been subsequently deposited. In the case of the large faults mentioned above, the line of fault causes a well-marked geographical feature; but this is usually not the case, the fault being quite invisible at the surface. This is the reason why there are more faults marked on the geological maps in mining districts than in others; there are not necessarily more faults in the coalfields than elsewhere, but mining operations have led to the discovery of more. It used to be imagined that most river valleys were originated by faults, but this is not really the case. The faults, which we now find near the surface, have probably been formed when the strata in which they occur were buried deep in the earth under other rocks which have since been denuded away, and it is most likely that they did not originally reach the surface at all. In this case it is obvious that they could not influence the direction of the rivers.

Where the disturbing forces have been very intense, reversed faults of a very extreme kind have been sometimes formed, masses of strata not only being pushed up the slope of the fault, but being thrust bodily over other strata. Such has happened in the Archean rocks of the north-west of Scotland on a gigantic scale. The surface over which strata are pushed in this manner is called a *thrust plane*.

As a rule, the older strata have suffered most disturbance by contortion and faulting. Probably in the very early times in which these strata were laid down, the disturbing forces, mainly due to shrinkage of the earth in cooling, were more intense, and they have moreover been exposed to these agencies during a longer period. In a geological map each colour represents one particular system, or formation, or set of strata, and in examining such a map the observer is struck with the irregular and confused manner in which the colours are laid on. There seems to be no order or method, in one place a colour occupies a wide area, in another a narrow broken strip, in others it occurs in small isolated patches. After what has been said it will not be difficult to understand why this is so. It is due, firstly, to the fact that the land surface is uneven; and, secondly, to the fact that the geological strata are inclined, bent, and faulted. Where a wide extent of country is occupied with one system, it is generally, though not always, because the country is rather flat and the strata approximately horizontal. When the colours are most confusedly mixed, it is often mountainous, with deep valleys cutting into and exposing strata that would otherwise be hidden, and the strata are frequently also highly disturbed. Instances of this may be seen by comparing the flat plains of Russia with central Europe on a geological map.

SUMMARY.—After deposition various changes occur in the strata.

They are hardened—
(*a*) by pressure of overlying beds;
(*b*) by infiltration of cementing material;
(*c*) by subterranean heat.

2. *Joints are developed;* generally two vertical sets at right angles. These joints are not due to crystallization, or, as a rule, to shrinkage, but to *strain* when the strata are upheaved or bent.

3. *They are inclined.* That they were not so originally is proved by rain and ripple marks, etc., on beds now vertical. The slope is called *dip*, the line at right angles to the dip is the *strike*, the termination of a stratum at the surface is the *outcrop*. The outcrop varies with the dip and surface contour.

4. *They are bent* into *anticlindls*, *synclinals*, *domes*, *basins;* and sometimes *inverted.*

5. Denundation forms *outliers*, and exposes *inliers.*

6. Fractures and movements produce *faults*, ordinary and reversed.

QUESTIONS.

1. Through what various stages of hardening have clay, shale, slate, sandstone, and limestone passed?

2. What is the chief cause of jointed structure? Why is it concluded that it has no connection with crystallization?

3. What reasons have we for believing that all the stratified rocks, whatever their position at present, were once horizontal?

4. What practical difficulties occur in connection with the determination of *dip?*

5. Explain the difference between *strike* and *outcrop*. Why is the latter so irregular?
6. Define *outlier*, *inlier*, *anticlinal*, *dome*, *fault*. Give examples.
7. What is meant by *axis plane?* What positions does it assume?
8. What difficulty is there in believing that river valleys originated in faults?

CHAPTER XVI.

CLASSIFICATION OF PLANTS AND ANIMALS.

As the remains of plants and animals which are found in the stratified rocks will be very frequently described in the following chapters, it is very important that every student of geology should understand the general principles on which plants and animals are classified, the relations of the various groups to each other, and the chief members of each group. There are so many thousands of different kinds of plants and animals that it is quite impossible to get an idea of them by the separate study of each; but by the labours of successive generations of naturalists, each carefully studying and recording the characters of a limited number, a large body of facts has been accumulated, and it has become possible to arrange them in groups, large and small, according to the characters which they have in common. Each separate kind of organism, whether plant or animal, which produces others like itself is called a **species.** Species which have a good many characters in common are grouped together into a **genus.** In naming a plant or animal two names are generally given; the first is the name of the genus to which it belongs, the second is the name of the species. Thus *felis leo* denotes an animal belonging to the genus *felis* and the species *leo*. *Felis tigris* denotes an animal of the same genus, but of another species. If the animal is common it has a popular name by which it is generally known: the two animals above-named are the *lion* and the *tiger*. Genera are grouped into **families.** The lion and tiger both belong to the family *felidæ;* the *felidæ* together with *canidæ*, *mustelidæ*, *ursidæ*, and other families form the **order** *carnivora*. Orders are grouped together into **classes**, and classes into **sub-kingdoms.**

It can be well understood that many different classifications are possible, according to the relative importance given to various distinctive characters, and naturalists are not altogether unanimous as to what is the best system of classification. For geological purposes it is best to adopt a simple classification, based as far as possible upon the characters of those parts which are most likely to be preserved in the fossil state—as, for instance, shells, bones, teeth, spines, scales, etc., in the animal kingdom; and in the vegetable, the leaves, woody tissue, and external markings.

It is quite impossible, and, indeed, unnecessary to give a full classification here; but we will now take the sub-kingdoms, seven in number, describe their leading characters, and mention in connection with each those classes, orders, families, or genera which are most important and interesting to the geologist. We begin with the most simply organized.

1. **Protozoa.** This sub-kingdom comprises, for the most part, minute organisms which seem to be nothing more than specks of living jelly. Some, however, secrete very beautiful calcareous shells in which they dwell. Such are the *Foraminiferæ*, which make up much of our chalk and some other limestones. They are found in rocks of all ages, and are still common, both in the sea and in the fine mud or ooze at the bottom. The word *protozoa* means "first life," and a member of this sub-kingdom, the *Eozoon*, is the most ancient fossil known. Another order of Protozoa, the *Radiolaria*, have a siliceous shell, but are otherwise very similar to the preceding.

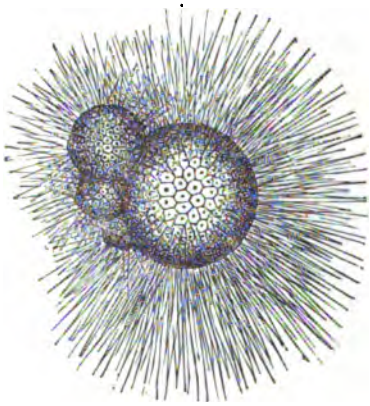


FIG. 108.—Foraminifer, *Globigerina bulloides*, magnified seventy diameters. This form is found floating in tropical and temperate seas.

2. **Cœlenterata,** or **Zoophites.** These are also jelly-like animals, but they have a definite mouth, with tentacles arranged

in a star-like fashion round it. Anemones and jelly-fish are well-known members of this sub-kingdom, but they are of no importance to the geologist, as they scarcely ever leave any traces of their existence in the rocks. Many individuals of this sub-kingdom live aggregated together in colonies on a common support. Such are the *sponges*, which are masses of gelatinous organisms located on a horny, calcareous, or siliceous framework. The first are those used for domestic purposes, but the last are most frequently found fossilized, owing to their hardness. They are very common in the chalk and other calcareous strata, both whole and fragmentary, their siliceous spicules being very common in the chalk. In some of the old rocks there are peculiar markings called *graptolites*, so called from their fancied resemblance to a quill pen. They are of various patterns, single and double, straight or bent, but they all consist of the impressions or markings of small rods, with regular notches or recesses in them, in which the zoophytes once dwelt. Another very important class is the *corals*. Some of these are solitary, and some are in colonies. They all secrete a strong case of carbonate of lime, which serves for their protection and support. They appear to have been very abundant in the old oceans, for many of our older limestones are chiefly made of them. Corals are best known to us as forming reefs and coral islands in shallow water in tropical seas; but many of the simple kinds live in deep water, and in

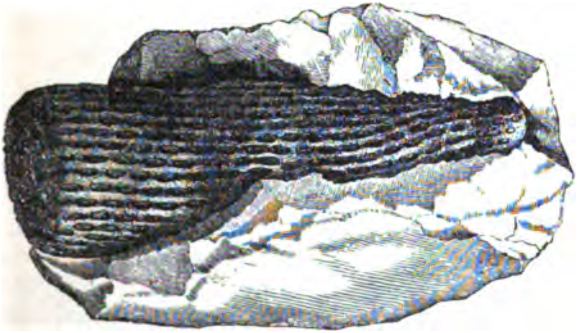


FIG. 109.—Ventriculites—fossil sponge (chalk).

temperate latitudes. The space inhabited by the zoophite is more or less circular in section, with divisions called *septa*, reaching from the circumference towards the centre. In the oldest rocks the corals have their septa in multiples of four, and, in the more recent, in multiples of six. Other corals consist of a number of tubes fixed together. All these members of the Cœlenterata are found in very ancient rocks; but while the graptolites soon died out, sponges and corals have continued to live on to the present day.

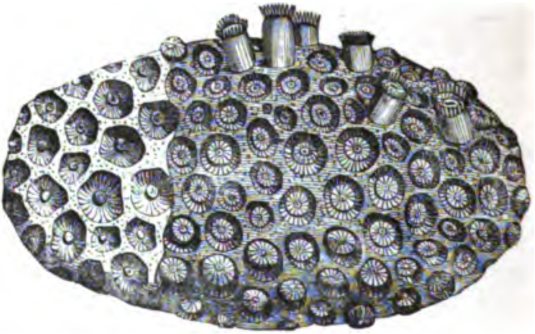


FIG. 110.—Coral. The left side of the figure shows the coral denuded of soft parts; on the right the animal matter is shown, while at the upper part several of the polyps are seen projecting.

Cœlenterata
- Sponges: *Ventriculites.*
- Corals: single, *Caryophyllites.*
  - reef-building, *Astrea*, *Porites.*
- Graptolites:

3. **Echinodermata** (*echinus*, a spine; *derma*, skin). The name indicates the characteristic external property. They possess mouth, digestive cavity, and a kind of circulation. They comprise the creatures popularly known as sea-urchins and star-fishes. The latter, forming the order *Asteroidea*, occur in Silurian rocks, are found more or less in all the geological systems, and still survive. The sea-urchins, *Echinoidea*, are typical members of the sub-kingdom; and their hard external crusts, with their knobs or tubercles, and perforations, arranged geometrically, make very noticeable fossils, which are especially

abundant in the chalk. The spines, however, are generally though not always detached. To this division also belong the *encrinites*, or sea-lilies. These were once, apparently, much more numerous than at present. They consist of a jointed stalk, often several feet in length, supporting a stony cup which contains the animal, which has long tentacles, also enclosed in calcareous material. Portions of their stalks are very common in the older limestones; as, for instance, in the Derbyshire encrinital limestone, which takes it name from them. The cups with their tentacles are less common, and it is quite exceptional to find an encrinite with stalk, cup, and tentacles all complete.

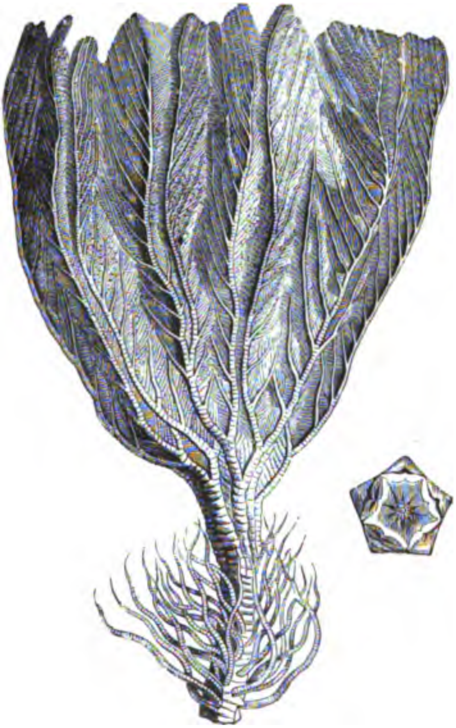


FIG. 111.—*Pentacrinus briareus* (an encrinite).

Echinodermata { Asteroidea : *Protaster.*
Echinoidea : *Galerites.*
Crinoidea : *Pentacrinus.*

4. **Annulosa**, or **Vermes**. The first name denotes that their bodies consist of a series of rings (*annulus*, a ring) or segments. As the second name denotes, they comprise what are commonly known as *worms;* and as they rarely become fossilized, the group is not very important geologically. Some

genera of one of the divisions, the Annelida, however, encase themselves in a calcareous tube. The best known of these is the *serpula*, whose tubes are found meandering over fossils in rocks as ancient as the Silurian system, and which still flourish, though in a dwarfed condition, at the present day. Some of the annelids also have left their tracks over and burrows through the mud and sand distinctly recognizable at the present day.

Annulosa	Serpula (tubes of). Arenicolites (tracks and burrows).

5. **Articulata,** or **Arthropoda.** This sub-kingdom comprises all creatures without a backbone which have jointed or articulated limbs. They are a considerable advance on the preceding groups, and have segmented bodies, with a complete nervous and circulatory system. The most important class, geologically, is the *Crustacea.* Their hard "crusts," or shells, are remarkably well adapted for preservation, and their aquatic habits have ensured their fossilization from the earliest times. The best-known Crustaceans of the present day are the crab, lobster, and shrimp; but the class includes a large number of tiny organisms, such as *cypris*, *estheria*, etc., together with barnacles, acorn shells, and wood-lice. The most remarkable order of fossil Crustaceans is the *trilobites*, now quite extinct. They had symmetrical jointed bodies, large compound eyes, and two lines or indentations running down them, giving them the three-lobed appearance from which they derive their name. They are extremely abundant in the older geological systems,

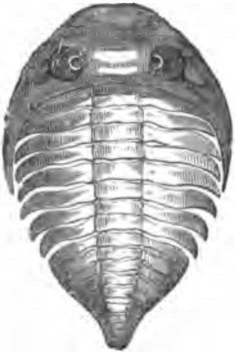


FIG. 112.—Trilobite.

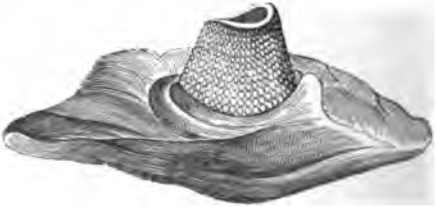


FIG. 113.—Compound eye of a trilobite.

and hundreds of beautiful specimens may be seen in our museums, but all without legs. It is, however, believed that, like all other Crustaceans, they had legs, but that after death they were easily detached, and were not adapted for preservation. They are entirely confined to the Palæozoic rocks. Lobsters and crabs came in as trilobites went out, and are abundant in the Mesozoic rocks, as well as in the London clay, where they are found very well preserved. The classes of centipedes and spiders, the latter including scorpions, appear in the Palæozoic systems. Insects are found also in these rocks; but, as a class, they are not adapted for preservation as fossils, though there are some remarkable exceptional cases in the more recent rocks, and a great number of comparatively recent ones are found embedded in amber, which is a fossilized gum.

Articulata
- Crustacea: trilobites, cypris, crabs, lobsters.
- Centipedes and millepedes.
- Spiders.
- Insects: bees, dragon-flies, beetles, flies, butterflies, and moths.

6. **Mollusca** (*mollis*, soft). These are soft-bodied animals, like the oyster, generally protected by a hard calcareous shell. The shell may consist of one piece, like that of the whelk or snail (*univalve*), or of two pieces hinged together, like the oyster or mussel (*bivalve*). The latter have no distinct head, and are all aquatic; the univalves live in air and water. Though less active in their habits than the members of the preceding sub-kingdom, their nervous organization is more advanced, as there is a distinct tendency for the nervous matter to aggregate into central masses, somewhat analogous to the brain of higher animals. The *polyzoa* are minute mollusks which live in colonies. Some species may be observed on the seashore, looking like a piece of seaweed, but which, on careful examination under a lens, is seen to consist of an aggregation of little cells, each containing

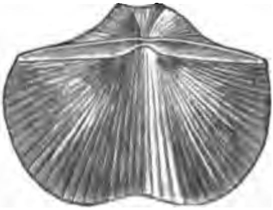


FIG. 114.—*Spirifer princeps* (Brachiopod).

its own separate living occupant. Extinct species of these are very common in limestones. *Brachiopods* ("arm-footed") are soft-bodied animals whose characteristic feature is a pair of long

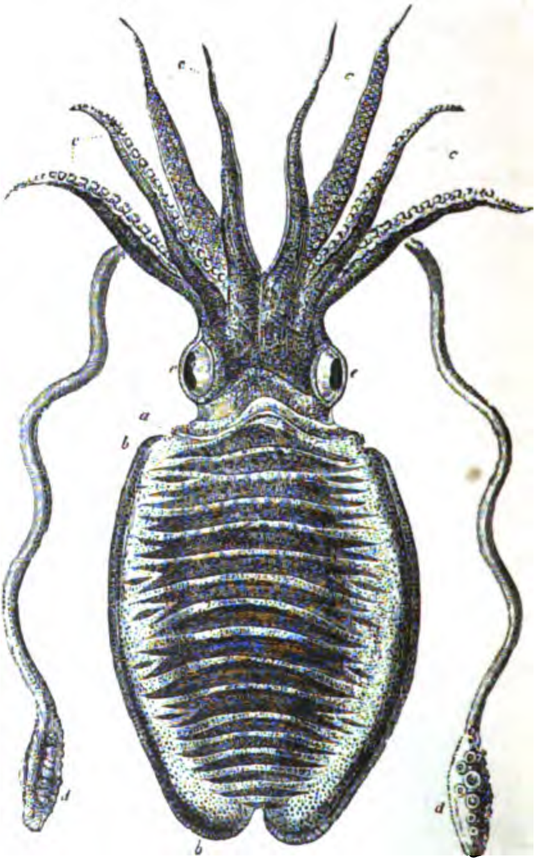


FIG. 115.—Cuttlefish.
c, arms bearing the suckers; *d*, tenacle-like arms; *a*, mantle; *b*, lateral fins; *e*, eye.

arms attached to the mouth, and often supported by large spiral frames, which, especially in the spirifers, nearly fill the shell. They are protected by a shell with two valves; but, on account of their special features, they are not generally recognized as "bivalves." (See Fig. 114.) The true bivalves, generally called *Lamellibranchiata* because their gills, or branchiæ, are in thin layers, or lamellæ, differ considerably from the Brachiopods; and their shells, which are the only parts with which the geologist has to deal, can be readily distinguished from those of the Brachiopods from the fact that the Brachiopod shell is bilaterally symmetrical, that is, it can be cut into two exactly similar halves, whereas the Lamellibranch shell cannot. Brachiopod shells were very abundant in the Palæozoic rocks, and have gradually declined until they are represented by only a few genera at the present day; while the opposite is the case with the Lamellibranchs. In Palæozoic times they were few and unimportant, and have become more and more numerous ever since. This is also the case with the Gasteropoda. Another very important class is the *Cephalopoda* ("head-footed"), so called because their organs of locomotion consist of tentacles arranged round the mouth. There is considerable variety among the Cephalopoda—some, like the cuttlefish of our own day, have a hard part inside, while others, like the nautilus, have it outside as a protection. They are very

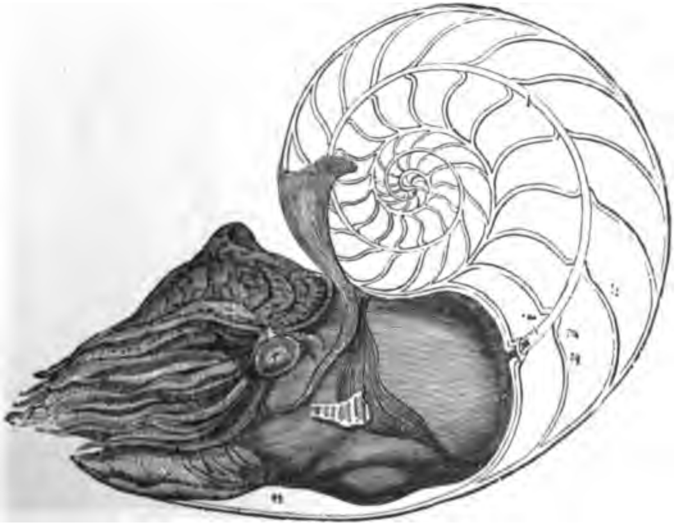


FIG. 116. Pearly nautilus, cut open.

abundant as fossils, and seem to have flourished in the Mesozoic era in much greater variety than at present. One very common form is the *belemnite;* this was an internal shell. Another is the *ammonite*, a beautiful external shell, which has been preserved both in great number and variety, and also in remarkable perfection. Like the gasteropod, it is a coiled shell; but in other respects it is quite different. It consists of a series of chambers, one in front of another, with a tube called a "siphuncle" connecting them. The junctions of the chambers are often indicated on the outside by a convoluted line. The mollusk inhabited the last and largest chamber, secreting a new chamber and vacating the old one as it grew too large for it. The chambers are sometimes empty, but are often filled with crystalline matter, such as carbonate of lime or iron pyrites. Ammonites vary much in size, some being the size of a shilling, and others three or four feet in diameter. Two other smaller and less important classes of the Mollusca were the *Pteropods*—thin fragile univalves living in the open sea; and the *Heteropods*, also free swimmers. Bellerophon and Maclurea belong to the latter class. Both classes have declined in importance, though they still survive.

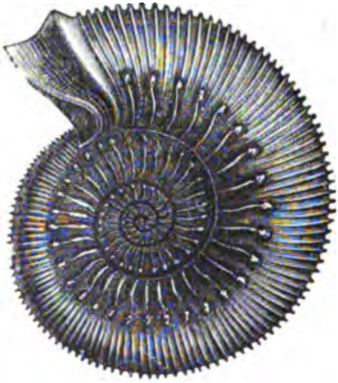


FIG. 117.—Ammonite.

Mollusca
- Polyzoa: *fenestella.*
- Brachiopoda: *rhynchonella.*
- Lamellibranchiata: *inoceramus.*
- Gasteropoda: *turritella.*
- Cephalopoda: *ammonites.*
- Pteropoda: *theca.*
- Heteropoda: *maclurea.*

7. **Vertebrata.** All the preceding sub-kingdoms belong

to the invertebrata, or animals without vertebræ, or backbone. The vertebrata, or animals with a backbone, are divided into five classes, viz., *Fishes*, *Amphibians*, *Reptiles*, *Birds*, *Mammals*. The first three, like all the invertebrata, are cold-blooded; the last two are warm-blooded, and are for the most part land animals. For geological purposes the characters most useful in the recognition and classification of *Fishes* are the scales, the tail, and the nature of the skeleton. These points enable us to place nearly all of them into one of the three following groups: (1) The *Elasmobranchii*, with either scattered isolated scales or none at all, a cartilaginous skeleton, and a tail with two unequal lobes, with the vertebræ continued into the larger (heterocercal); (2) the *Ganoidei*, with hard enamelled scales, skeleton ossified or cartilaginous, and heterocercal tails; and (3) the *Teleostei*, with ordinary scales, ossified skeleton, with biconcave vertebræ, and symmetrical (homocercal) tails. The Ganoids were very abundant in Palæozoic times, and comprise the characteristic fishes of the Old Red Sandstone; the Elasmobranchs, which include the sharks and rays, were most common in Mesozoic times, being represented by the Hybodus, Acrodus, etc.; their hard enamelled teeth are common in the chalk and London clay.

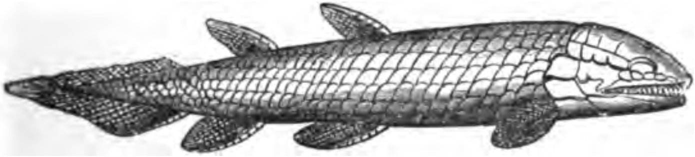


FIG. 118.—Ganoid from Devonian strata.

The *Teleostean* group appear late in the Mesozoic era, but are not common till Tertiary times are reached. The *beryx* found in the chalk is an early example.

Amphibians appear somewhat later than fishes, being first found in the Carboniferous system. The earliest traces consist of footsteps, which are very characteristic and readily recognized. The Labyrinthodonts flourished at the end of the Palæozoic and beginning of the Mesozoic eras. Frogs and toads do not appear till Tertiary times.

Reptiles can be distinguished from amphibians by the articulation of the skull to the vertebræ, the complexity of the lower jaw, and by the teeth having one fang. They first appear at the end of the Palæozoic era, in the Permian rocks, and reach their maximum in the middle of the Mesozoic era, of which they are the most characteristic fossils. Some gigantic forms, like the *Plesiosaurus* and *Icthyosaurus*, were marine (*Enaliosauria*); the *Mososaurus* and *Telerpeton* were huge lizards; the *Teleosaurus*, a crocodile; the *Iguanodon* and *Megalosaurus* were land reptiles (*Dinosauria*); and the *Pterodactyl* was a flying reptile. *Snakes* first appear in the London clay. *Turtles* are Mesozoic. *Tortoises* are not found below the Tertiary strata.

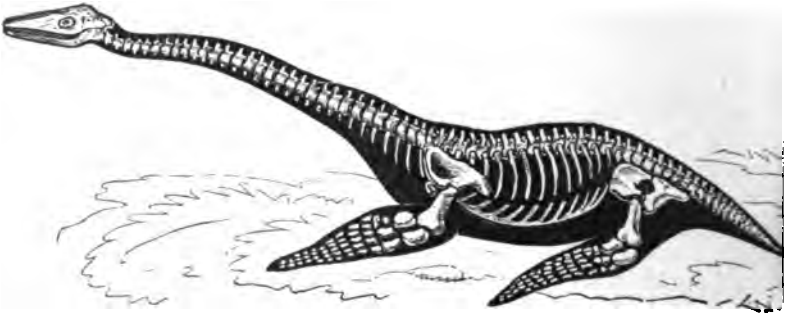


FIG. 119.—Plesiosaurus, a fossil reptile.

Birds first appear in the Upper Oolite, but footprints probably made by them appear in older strata. The earliest bird, the *Archæopteryx*, has a curious mixture of characters, such as teeth and a jointed tail, which are never seen in birds now. Bird fossils are never abundant; they are rarely buried in sedimentary deposits, and their light, porous bones readily decay. They are, however, fairly common in Tertiary strata.

Mammals, or animals which suckle their young, comprise the quadrupeds, together with some sea animals, such as the *seal*, *walrus*, and *whale*. The details of their skeletons present numerous special features which easily differentiate them from the other vertebrates. As most of them live and die on the land, their remains are much less abundant than most of the preceding divisions. Among the lowest of the mammals are the marsupials, including the kangaroo and its relatives. They are the first to appear in the geological record, being found in the Trias, and afterwards in the Oolite. The higher mammalia are not found till the Tertiary period, when gigantic forms of the elephant order, with others, became common; and although some of the larger mammalia have become extinct, the class has been continually developing and increasing till the present day.

It is impossible to arrange all the forms of animal life in an order-of-merit list, as it were, placing the most simply organized at the bottom and the most highly organized at the top, because it often happens that an animal is elaborately organized—that is, it has many special arrangements suited to supply its needs—but it is built on what may be considered an inferior model or plan. Such, for example, is the case with an insect as compared with a fish. The insect appears to be more highly finished and elaborated, but the fish, owing to the arrangement of its skeleton and nervous system, belongs to a higher type. The sub-kingdoms are founded on the type. All the creatures in the same sub-kingdom are modifications of the same type; but the plan is worked out in very diverse ways, so that there is plenty of room for divergence in each sub-kingdom. The sub-kingdoms can, therefore, be arranged in order of merit, as above, according to the simplicity or elaborateness of the type, and the various classes in the sub-kingdoms according to the special way in which the type is worked out. Thus, in the sub-kingdom vertebrata, we consider the mammals above the birds, birds above reptiles, and so on.

Regarding the animal kingdom from this point of view, it is very interesting to note when the various sub-kingdoms and orders first appear in the strata and when they become common. In doing this we must bear in mind how imperfect the record is; and that, though any particular order is not known till a certain period, yet it is possible that future discoveries may prove that it existed long before. Now, although the very oldest known fossil of all belongs to the *Protozoa*, yet all the invertebrate sub-kingdoms appear on the scene in times so ancient that it would not be safe to speculate on them. When we come to the vertebrata, however, we can observe the historical succession of the five classes. The most lowly vertebrata, fishes, appear first; then the amphibia; then reptiles, birds, mammals. Of the mammals, the lowest, the marsupials, come first; the highest, man, last. It is therefore thought possible that, if the most ancient rocks were not so much metamorphosed, and if many more of them could be examined, it might be discovered that a similar succession holds good for the invertebrata, and that, from the time when the earth's surface was first able to support life till the present time, there has been a steady and gradual advance from the eozoon up to man.

Plants are divided primarily into two great divisions, those which do not flower and fruit, *Cryptogams;* and those which do, *Phanerogams.*

Cryptogams may be merely cellular, as sea-weeds, lichens, and fungi; or vascular, as ferns, mosses, lycopodium, and "horsetails."

Phanerogams comprise *Gymnosperms* ("naked-seeded"), including the conifers, or firs and pines, and cycads, which do not have their seed enclosed in a special receptacle, and the *Angiosperms* ("seeds in vessel"), which have their seeds protected by a seed-vessel, or ovary. This group is by far the largest, most important, and highly developed, and comprises most of the plants with which we are most familiar. They are *Endogens* or *Monocotyledons,* such as grasses, palms, and lilies; and *Exogens* or *Dicotyledons,* such as the oak, poplar, and our ordinary trees and shrubs.

In the case of plants, we have the same order of appearance in the strata. First in the most ancient rocks, such lowly cryptogams as sea-weeds and mosses (*Oldhamia,* etc.); then a great variety of gigantic cryptogams, such as *Lepidodendron, Calamites,* and *Stigmaria,* of the coal measures, with conifers; cycads, such as *Zamia;* and finally, in comparatively late times, all kinds of Angiosperms, which are now predominant.

ANIMAL KINGDOM.

SUB-KINGDOM.

I. **Protozoa**: Foraminiferæ, Radiolaria.
II. **Cœlenterata**: Sponges, Graptolites, Corals.
III. **Echinoderms**: Star-fishes, Sea-urchins, Encrinites.
IV. **Annulosa**: Serpula.
V. **Articulata**: Crustacea, including trilobites, cypris, crabs and lobsters, centipedes, spiders, insects.
VI. **Mollusca**: Polyzoa, Brachiopoda, Lamellibranchiata, Cephalopoda (including belemnites and ammonites), Pteropoda, Heteropoda.
VII. **Vertebrata**:
  (1) *Fishes*: Elasmobranchii, Ganoidei, Teleostei.
  (2) *Amphibians*: Labyrinthodonts.
  (3) *Reptiles*: Plesiosaurus, etc., Crocodiles, Pterodactyl, Snakes, Turtles.
  (4) *Birds.*
  (5) *Mammals.*

VEGETABLE KINGDOM.

SUB-KINGDOM.

I. **Cryptogams**:
  (1) *Cellular*: sea-weeds, lichens, fungi.
  (2) *Vascular*: ferns, mosses, lycopodium, horse-tails.
II. **Phanerogams**:
  (1) *Gymnosperms*: conifers, cycads.
  (2) *Angiosperms*:
    (*a*) Endogens or monocotyledons: grasses, palms, lilies.
    (*b*) Exogens or dicotyledons: oak, poplar, etc.

QUESTIONS.

1. Define *species*, and explain the general principles of the classification of animals, and the difficulties which beset it.

2. Compare the *Protozoa* with *Cœlenterata*.

3. In what respect do the very ancient corals differ from those of the present day?

4. Give an account of *encrinites*, *serpula*, *trilobites*, and state to what sub-kingdoms they belong.

5. How is a *brachiopod* distinguished from a *lamellibranch*, and a *gasteropod* from a *cephalopod*? Why are *polyzoa* placed so much higher in the scale of life than *graptolites*?

6. Classify the vertebrata, and distinguish between a reptile and an amphibian.

7. What general facts have been observed with regard to the appearance in time of the different classes of vertebrata? Give illustrations.

8. How are plants classified? To what divisions do the following belong:—mushroom, pine tree, barley, fern, primrose, tulip?

CHAPTER XVII.

THE GEOLOGICAL SYSTEMS.

MOST authorities are now agreed that the earth was at some former, though very remote, period in a molten condition, and that it has reached its present state by a gradual process of cooling. When it was completely molten the atmosphere was very different in composition and character from what it is at present, as it certainly contained a great variety of substances, including water, which are now either liquid or solid. For a long period after it began to solidify, the solid matter was, of course, nothing but igneous rock; but as time went on, and the earth's solid crust became thicker and cooler, water gradually condensed and fell, and accumulated more and more on the surface. By the action of this water the rocks already formed would be gradually worn away and deposited as sediment, and so the first aqueous rocks appeared. From those far-off times to the present this process has continued, and the whole of the existing series of stratified rocks is the final result of it. Every particle of matter in them must have originally existed in the molten earth; afterwards, in the igneous rock formed by the surface solidification; and, finally, after denudation from the latter, in the stratified rocks, though not necessarily in the position in which it now rests, as the stratified rocks, to an increasing degree as we ascend in the series, are themselves in a great measure derived from previously existing strata.

From the above considerations, it will be evident that it is not at all likely that much, if any, of the original solid surface of the earth is now in existence, or that we can even hope to find many traces of the first-formed aqueous rocks. In all probability they were denuded away ages ago. At this remote period, standing at the very beginning of geological time, the action of some of the geological agencies would be more intense than they are at the present day. We can imagine that the thinner crust would be more easily and more frequently broken through by volcanic forces; that the heated air, charged with steam and carbonic acid, and subject to violent storms and disturbances, would produce greater chemical and physical effects; and that the earlier showers, falling upon the still hot surface, and bringing down with them from the air carbonic acid and other corrosive gases, would erode and dissolve the rocks to a much greater extent than they do in our comparatively settled times. It is no wonder, then, that the bottom of the pile of stratified rocks is regarded with special interest, and that observers have fancied that they saw in these strata evidences of the intense action of the forces of that earliest time.

Inasmuch as most of the stratified rocks are derived from the waste of previously existing stratified rocks, it follows that the series must be very imperfect, especially when studied in any particular and limited area. The formation of stratified deposits in one place implies an equal amount of denudation in another, and the only way to get an idea of the whole series is to piece the various deposits together. Even then there are many periods unrepresented, many missing links in the chain, though these missing links become fewer and fewer as we extend our studies over a wider field. Looking generally at the whole series of stratified rocks, we observe two points at which the break is particularly noticeable, and these two breaks serve conveniently to make our first large divisions of the stratified rocks, viz.:—

1. Tertiary or Cainozoic ("recent life").
2. Secondary or Mesozoic ("middle life").
3. Primary or Palæozoic ("ancient life").

Each of the above large groups is subdivided into smaller divisions, called "systems."

Cainozoic	Post-Tertiary.	
	Tertiary.	
Mesozoic	Cretaceous.	
	Jurassic	Oolite.
		Lias.
	Trias.	

Palæozoic	Permian.
	Carboniferous.
	Devonian.
	Silurian.
	Cambrian.
	Archæan and Pre-Cambrian.

The most accessible, the most complete, and the most easily understood are the most recent, and there would be some advantage in beginning our systematic study of the stratified rocks at that point; but it will be best, on the whole, to treat them as a book to be read, and begin at the beginning, or as near to it as possible.

As has been already explained, the great point of interest in our study will be the varied and constantly expanding succession of animal and vegetable life which will pass before us, becoming more and more highly developed and more multifarious as we proceed. Naturalists have now no doubt that the plants and animals which we find living on the earth at the present time are the direct descendants of those whose remains we find embedded in the rocks; and that, if we could have displayed before us a complete set of the earliest strata, we should find in them traces of the original forms of life from which all others were gradually evolved. With one dubious exception, however, the first fossil-bearing rocks, the Cambrian, disclose to us a series of remains which are very far in advance of what we should expect to find as representatives of the beginnings of life. Life originated on the earth, there is little doubt, at some time between the formation of the first solid crust and the beginning of the Cambrian period, but the Pre-Cambrian strata are too scanty and too much metamorphosed to throw much light on the question.

SUMMARY.—1. If the molten theory of the earth be correct, the first-formed rocks were all igneous. From the denudation of these, the aqueous rocks were in the first instance derived, though many have been immediately derived from previously existing aqueous rocks.

2. We cannot be certain that any of the first-formed aqueous rocks are known to us, but we cannot doubt that the various geological agencies, atmospheric, aqueous, and volcanic, were more intense in very early geological times.

3. On grounds, partly physical, partly palæontological, the stratified rocks have been divided into three large groups, *Cainozoic*, *Mesozoic*, *Palæozoic*; and these into twelve systems.

4. Although remains of plants and animals have at all times been embedded in the rocks, yet, owing to denudation, metamorphism, and inaccessibility of the strata, we have been able to discover very little of the very earliest life.

QUESTIONS.

1. Describe the first-formed solid rocks of the earth, and the conditions under which the first aqueous rocks were probably laid down.
2. Why is it unlikely that we shall ever be able to find out much about these very early strata?
3. Name the three groups of stratified rocks, with the systems included in each division.
4. To what extent do fossils give us information as to the succession of life on the earth? and why is this information very incomplete?

CHAPTER XVIII.

THE ARCHÆAN AND PRE-CAMBRIAN ROCKS.

THE rocks which lie below the Cambrian, though of comparatively limited extent on the surface, evidently represent a vast period of time. The fossils which are presented to our view in the Cambrian rocks embrace specimens of all the sub-kingdoms except the Mammalia; and, according to the evolution theory which is now universally accepted by naturalists, all these very unlike organisms must have been evolved from the lowest organized matter during "Pre-Cambrian" times. Some of the old rocks on which the very earliest existing stratified rocks repose may be portions of the solid rock which was formed when the molten earth first began to solidify. Between the time when these were formed, and that when the lowest deposits of the Cambrian were laid down, life appeared on the earth, and through long succeeding ages was modified and differentiated into the variety of creatures found in the Cambrian rocks. It is impossible to say how long a time this was—possibly it was as long a period as that which has gone by since. The comparatively small amount of the stratified rocks of that early period which remain accessible is not surprising when we remember that the older rocks have been more exposed to denudation, all the succeeding systems having in fact been largely built up from their remains, and that they are also more likely to be covered up because they lie below all the rest.

In considering these "Pre-Cambrian" rocks, we must discriminate between the fundamental igneous rocks which form the platform or foundation, and those rocks which, though much altered in appearance, are undoubtedly stratified, and which rest upon them.

To the former class belong the *gneisses*, which seem to be pretty much the same all the world over, wherever they are to be seen, and it is to these rocks and their accompaniments which Sir A. Geikie proposes to restrict the term *Archæan.* This Archæan gneiss is laid bare in many districts, in the Hebrides, in Ross and Sutherland, and in North America; and although these local exposures may have different names, and may differ slightly among themselves, yet there is sufficient general resemblance between them to suggest that they all belong to one great underlying mass, although it is impossible to prove it.

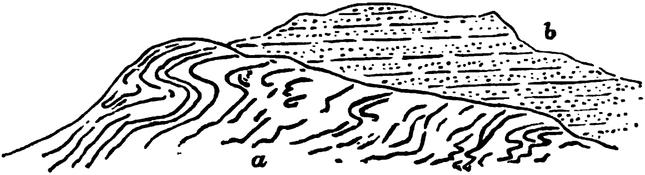


FIG. 120.—Cambrian rocks (*b*) resting on Archæan gneiss (*a*) in N.W. Scotland.

When some of these gneissic areas are carefully examined, it is often found that in certain portions the foliated structure seems to die out, and the rock then assumes many of the characters of an igneous eruptive rock. It does not, however, possess the structure of an ordinary lava, inasmuch as it is perfectly crystalline, and has no bands of fragmental matter or of scoriæ. It rather resembles *a plutonic* or deep-seated igneous rock than a rock which has been poured out at the surface, though very possibly it may have been once continuous with a surface outflow, which was afterwards denuded away before any known existing strata were deposited upon it. In fact, it is thought possible that these close-grained crystalline areas and bosses may be the deep-seated portions of the molten rock which once filled and flowed from ancient volcanic craters; while the more foliated portion, or "fundamental gneiss," is what we may call the plutonic portion of great surface lava-flows which have long been removed.

All the gneiss of the north-west of Scotland, and even that of Ireland, is intersected by an intricate and very extensive series of dykes of basic rock. None of these extend up into the overlying stratified deposits, and all of them have been affected by the forces which have squeezed, folded, and broken the fundamental gneiss. This proves them to be anterior to the period of the deposition of the Pre-Cambrian stratified rocks, and bears witness to the long duration of Archæan time. It is probable that these dykes are the vestiges of widespread and long-continued volcanic outbreaks, and that they were once continued upward into great outpourings of lava, which, so far as we can tell, were nearly all denuded away before the very lowest of the now existing stratified rocks was deposited. The only remains of this ancient lava perhaps exist as pebbles in the lowest portion of the Torridon sandstone.

In the north-west of Scotland, resting inconformably on the gneiss, and based upon a conglomerate made up of its pebbles, are the thick beds of the Torridon sandstone, a series some thousands of feet in thickness, and possibly of Cambrian age, and itself overlaid unconformably by the Durness limestone and quartzites.

The Highlands of Scotland east of the tract of Archæan gneiss are largely composed of a confused and complicated series of schists and other metamorphic rocks. They contain no fossils, and they have been exposed to such prolonged contortion, metamorphism, and denudation, that it is almost impossible to disentangle them and establish a true order of succession. Many are probably Pre-Cambrian, some may be contemporaneous with the Torridon and Durness series, and some may be still more recent.

In Tyrone county, in Ireland, there are lavas, vesicular, schistose, and metamorphosed; agglomerates of lava fragments, and tuffs apparently derived from lavas, the whole series flanking a ridge of Archæan gneiss with intercalations of sedimentary and intrusions of igneous rocks.

There is a noteworthy gneissic district in Central Anglesey which is very similar to that of North-West Scotland, and which, though originally considered by Sir A. Ramsay to be altered Cambrian, is now believed by Sir A. Geikie to be Archæan;

while resting on it is a series of quartzites, schists, slates and grits, with intrusive and interbedded igneous rocks, the whole much fractured and very similar to the Highland and Irish Pre-Cambrian series.

In Shropshire, the ridge which stretches from the Wrekin on the north to Caer Caradoc on the south is claimed by Dr. Callaway, apparently with good reason, as Pre-Cambrian. It consists of acidic lavas and volcanic breccias and tuffs. Dr. Callaway maintains that the overlying unconformable quartzite itself passes under fossiliferous Cambrian limestones. This suggests, though it does not prove, that it is much older than the Cambrian; and Dr. Callaway has bestowed on it the local name of Uriconian, from the ancient Roman town of Uriconium, whose ruins are hard by.

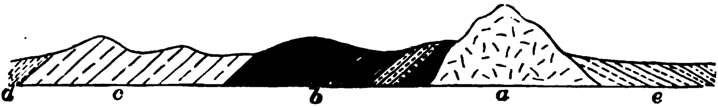


FIG. 121.—Malvern Hills (Phillips) Archæan gneiss, etc., *a*, with Cambrian and Silurian strata on the west, *b*, *c*, *d*, and Triassic on the east, *e*.

At St. David's, in Pembrokeshire, an extensive series of these Pre-Cambrian rocks exists;—granite and gneiss predominating in the lower (*Dimetian*) group; volcanic rocks in the middle (*Arvonian*); and slaty rocks on the upper group (*Pebidian*). In the Malvern Hills there is a central ridge that is probably Archæan hornblendic gneiss; and in Leicestershire, rising like an island among much later rocks, is the district of Charnwood, composed of what are probably Pre-Cambrian crystalline and volcanic rocks.

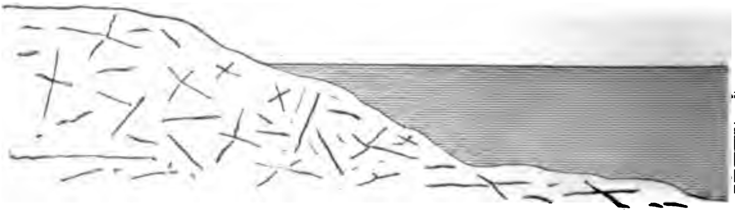


FIG. 122.—Rocks, probably of Pre-Cambrian age, overlaid unconformably by Triassic marls, in Leicestershire.

These fundamental rocks, the basement of gneiss with schists above, are found all over the world. Much of the Dominion of Canada consists of them. Here there is a lower division, called *Laurentian*, consisting of gneiss and granite, schists, limestones, etc. In the limestones there are found curious ramifications of serpentine and other minerals, which Sir J. Dawson and other naturalists have considered to fill the hollows once occupied by a gelatinous organism, to which they have given the name of *Eozoon* (= dawn of life). If this is really a fossil, it represents the very earliest known form of life. Many authorities, however, regard it with doubt. The higher division is known as the *Huronian ;* it is mainly gneiss, but there are various other rocks interstratified with it. These Pre-Cambrian strata of Canada suggest in several ways the existence of organic life at the period. It is difficult to know how the limestones could be formed without it, and large deposits of *graphite* must have been derived from vegetable matter.

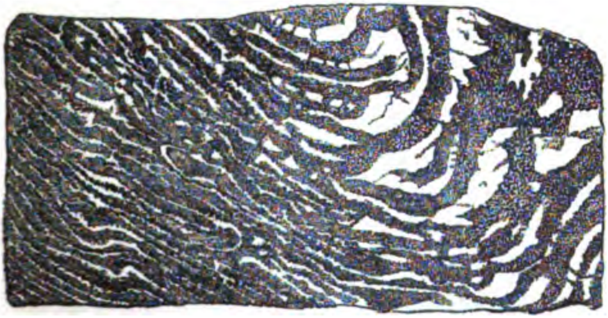


FIG. 123.—*Eozoon Canadense*, natural size.

Archæan rocks of similar character form the cores of the Alleghanies, and of many of the Rocky Mountain ranges in the States, and they underlie the Palæozoic rocks in the South Island of New Zealand, where, in Otago, they rise into industrial importance as a gold-bearing series.

SUMMARY.—The so-called Pre-Cambrian may be conveniently divided into Archæan and Pre-Cambrian proper, the latter being partly of aqueous origin, greatly metamorphosed as a rule, and interbedded with, and broken through by, igneous rock. They represent an enormous period of time. It by no means follows that the beds named under the various localities in the following table are contemporaneous; they simply belong to the Pre-Cambrian system.

PRE-CAMBRIAN, INCLUDING SOME ARCHÆAN.

Scotch Highlands.	Tyrone.	Anglesey.	Shropshire.	Pembrokeshire.	Leicestershire.	Canada.
Schists, quartzites, and limestones.	Lavas, volcanic agglomerates, tuffs, sedimentary rocks.	Quartzites, schists, slates, grits.	(*Uriconian*) quartzites —— lavas, breccias, tuffs.	(*Pebidian*) slates, (*Arvonian*) volcanic rocks. (*Dimetian*) granite gneiss.	Volcanic rocks and slates.	(*Huronian*) gneiss and stratified rocks. (*Laurentian*) schists, limestones, granite.

ARCHÆAN.

Fundamental gneiss and other igneous rocks, intersected by ancient dykes, forming the base upon which the metamorphosed Pre-Cambrian rocks repose.

QUESTIONS.

1. What reasons have we for believing that a very long period elapsed between the time when stratified rocks first began to be formed, and the commencement of the Cambrian period?
2. Distinguish between Archæan and Pre-Cambrian as defined by Sir A. Geikie.
3. Describe the fundamental gneiss.
4. Briefly describe the Pre-Cambrian rocks of three British localities.
5. How are the Pre-Cambrian rocks of Canada classified? What point of special biological interest is connected with them?

CHAPTER XIX.

THE CAMBRIAN SYSTEM.

THE precise limits of this system have been the subject of much discussion. In the early days of geological research two of the greatest of our English geologists were approaching the study of these rocks from two different directions; Sir R. **Murchison** was working downwards from the newer rocks of

Herefordshire, and Professor Sedgwick was working upwards from the older rocks of North Wales. Murchison named his system of rocks the Silurian, Sedgwick called his Cambrian, and in the end each explorer found himself claiming and annexing to his own particular system strata claimed by the other. Murchison was of opinion that, with the exception of certain beds, which were then thought to be unfossiliferous, all should be included in the Silurian; while Sedgwick, on the other hand, considered that all Murchison's Lower Silurian were really Cambrian. There was much to be said on each side. The unfossiliferous Longmynd rocks were markedly distinct from those above them, and seemed to belong to a much earlier period; while the first real stratigraphical break occurs at the top of what we now call the Lower Silurian. Neither view is accepted by most authorities now; the line being drawn, mainly on fossil evidence, at an intermediate horizon. This is exhibited in the following table of the Silurian and Cambrian systems.

Murchison's Silurian	Ludlow beds		Silurian
	Wenlock beds		
	Upper Llandovery		
	Lower Llandovery	Sedgwick's Cambrian	
	Caradoc and Bala		
	Llandeilo		
	Arenig		
	Tremadoc slates		Cambrian
	Lingula flags		
	Menevian beds		
	Longmynd beds		

The Cambrian system, as thus defined, consists of a vast succession of reddish grits, conglomerates, shales, slate, and quartzite; but there is no gneiss, and there are few schists, and fewer limestones. They are all more or less shallow-water deposits, as can be seen, not only from their composition and texture, but by the presence of current-bedding, ripple-marks, rain-pittings, holes, and tracks of worms and footprints and markings of other creatures, probably crustaceans.

The system was named by Professor Sedgwick from the ancient name of Wales, where it is most fully developed, and where it was first studied. Its various beds attain the enormous gross thickness of twenty-five thousand feet, or more than four and a half miles. Now, as the top beds were formed under water, it might be supposed that this water must at least have been four and a half miles deep when the lowermost beds were deposited. This, however, could not be the case, as these beds are conglomerate, made up of pebbles cemented together, and we cannot conceive how such material could be formed anywhere else than in very shallow water. The explanation, no doubt, is, that these rocks, like all similar series, were originally deposited when the land was slowly sinking, so that the water, though shallow, was never actually filled up. The same thing seems to be happening at the present day, where the conditions are similar; that is, in deltas and other places where sediment is rapidly accumulating. This has been proved in the deltas of the Mississippi, Po, Nile, and Ganges, where deep borings, made for water-supply, pass through hundreds of feet of shallow-water strata; and it is not unlikely that the depression of the Netherlands and the formation of the Zuyder Zee is due to a gradual sinking of the Rhine delta, brought about by the weight of the alluvial deposits.

Although not bearing traces of such extreme metamorphism as the underlying system, the Cambrian rocks show their antiquity by their contorted, tilted, and faulted condition; and it has been observed that, in many cases, even their fossils are distorted. The lowest Cambrian strata rest unconformably upon an irregular worn and denuded surface of the Pre-Cambrian rocks, and their lowest bed consists of a conglomerate derived from the older system. Fossils have been found throughout in most localities, but much more abundantly in the upper division. It has been already remarked that these fossils do not seem by any means to belong to what might be considered the original elementary forms of life. On the other hand, we find representatives of all the highest invertebrata, such as *trilobites* and *brachiopods*. These classes are exceedingly abundant in the Palæozoic systems; the former, however, being limited to those systems, while the latter are represented by living species. The trilobites are especially characteristic of the Cambrian and Silurian systems. Though their special features enable them to be readily recognized, they differ very much among themselves, especially those of the Cambrian rocks. For instance, the *Agnostus*, one of the earliest trilobites, was about a quarter of an inch long, had no eyes, and only two segments, while the *Olenus* and *Paradoxides* were from one to two feet long, had compound eyes, and more than twenty segments. Their backs were protected by a shield, but their legs are always absent, though their footprints are believed to have been recognized.

The lowest Cambrian rocks are brought up by an anticlinal fold to the South of Shrewsbury, where they form a wild high-lying region called the **Longmynd**, and they appear again near Harlech in North Wales. The two areas are probably continuous, but are covered by later strata in other places. These Longmynd rocks become finer and finer upwards, and further north, at Penrhyn and Llanberis, they pass into the fine-grained slates which are worked in enormous quarries. In Pembrokeshire the rocks of the same age are reddish sandstones resting unconformably on Archæan rocks.

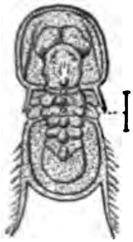


FIG. 124.—Agnostus.

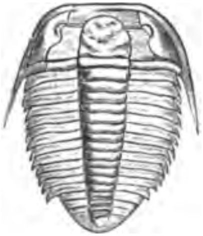


FIG. 125.—Olenus.

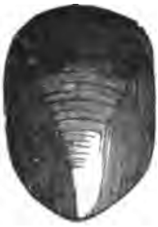


FIG. 126.—Lingulella.

The strata above described were in Murchison's time thought to be unfossiliferous, but careful research has brought numerous fossils to light, among them the trilobites *Agnostus* and *Olenus* and the brachiopods *Lingulella* and *Discina*. Markings of a peculiar radiating pattern found in rocks apparently of this age, in Wicklow, are believed to be impressions of a sea-weed (*Oldhamia;* Fig. 124); and reticulated markings are attributed to a sponge, and called *Protospongia.* It is possible, however, that they are both inorganic.

The red sandstones of Pembrokeshire pass upwards into a series of slate and flagstones, called the **Menevian beds,** from Menevia, the old Latin name for St David's. They are very fossiliferous, and have yielded trilobites which are not found in more recent strata. The largest and most characteristic of these is *Paradoxides.* *Orthis* is a noticeable brachiopod.

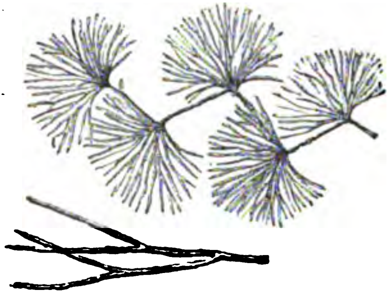


FIG. 127.—Oldhamia.

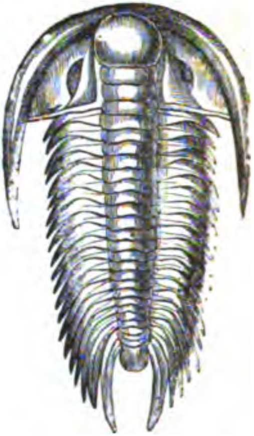


FIG. 128.—Paradoxides.

The Menevian beds pass upward conformably into the **Lingula beds,** so called from an abundant and characteristic brachiopod, now called *Lingulella,* and probably identical with a species still living. The trilobite *Olenus* is found, a crustacean called *Hymenocaris,* and *Orthis.* There are also traces of unrecognizable vegetable matter. The slates which are worked in the quarries at Festiniog in North Wales belong to this epoch.

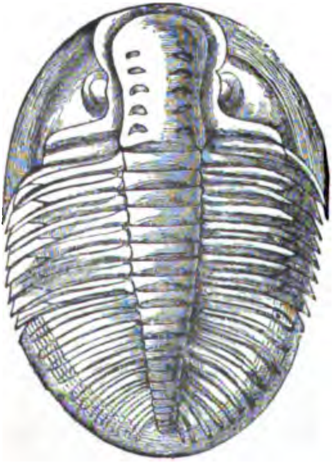


FIG. 129.—Ogygia Buchii.

The highest division of the Cambrian is the **Tremadoc slates.** They are found in force near Tremadoc, and also near St. David's, where they rest on the Lingula beds. They have yielded numerous fossils at each locality. *Agnostus* and *Olenus* are still found; but many new trilobites, including *Asaphus*, *Angelina*, and *Ogygia*, make

THE CAMBRIAN SYSTEM.

Scale: 1 inch = 4,000 feet; about 20,000 feet (and upwards).

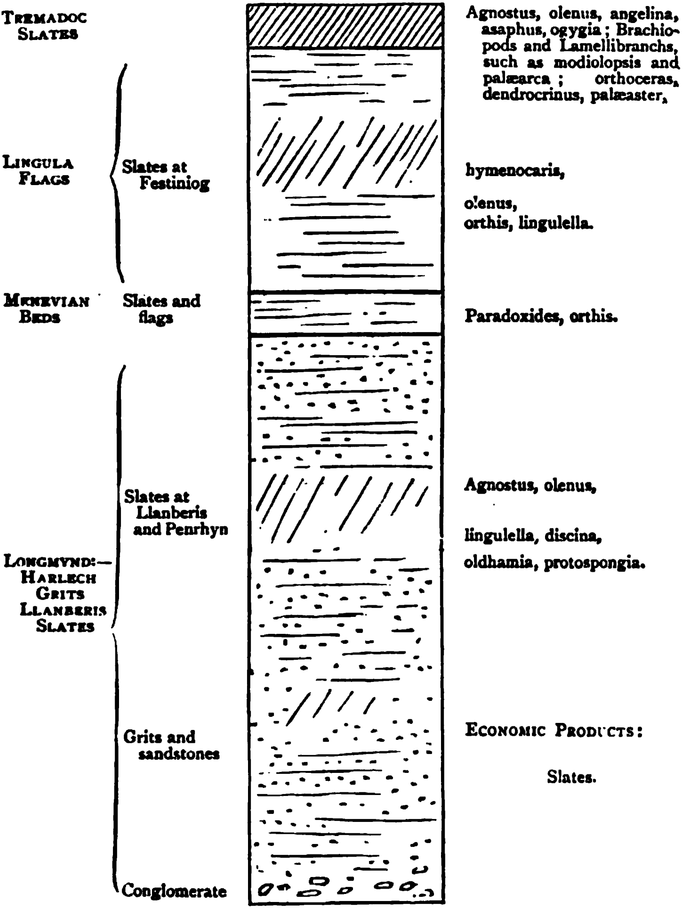


FIG. 130.

their appearance. Brachiopods, both old and new, also flourish; and several small species of Lamellibranchs have been found, belonging to the genera *Modiolopsis*, *Palæarca*, and others, all the species being restricted to the Tremadoc slates. Cephalopods now appear, being represented by *Orthoceras*, one of the straight-shelled kind. A crinoid, *Dendrocrinus*, and a star-fish, *Palæaster*, have also been found.

With the Tremadoc slates the Cambrian system ends. The next beds, though not always uncomformable, have so many new fossils, and so few of the old ones, that they make a convenient base or starting-point for the next system.

QUESTIONS.

1. What various classifications have been proposed for the Cambrian and Silurian rocks? How did the difference of opinion arise? and how has the question been settled?
2. How is the occurrence of an immense pile of shallow-water deposits one above another to be explained? Give modern instances to illustrate the question.
3. Describe the Lower Cambrian rocks and their fossils.
4. Give a description of the organization of the trilobites. In what respects do they differ from each other? Name the chief Cambrian species.
5. What brachiopods are found in the Cambrian rocks?
6. What are the various divisions of the Upper Cambrian? and where may they be studied?

CHAPTER XX.

THE SILURIAN SYSTEM.

WALES and the west of England, owing to the long-continued labours of Murchison and Sedgwick, alluded to in the preceding chapter, constitute the classic ground of the geologist. Murchison commenced his work in 1831; in 1835 he named the system "Silurian," after the Silures, an ancient tribe which once inhabited the region; and in 1838 he published a complete account of it, in a ponderous volume of eight hundred pages. Nearly all the beds there described and illustrated were examined and named by Murchison himself, and they are still considered the typical divisions of the system, to which Silurian strata in other parts of the world are, if possible, referred. Strata of

Silurian age make up most of the "Lake Country," and the most rugged and picturesque parts of Ireland and Scotland. The Scotch Highlands, however, are so contorted, fractured, displaced, and metamorphosed, that it has so far been found quite impossible to arrange all their component strata in chronological order. There is very little doubt, however, that some of them are of Silurian age, though others are probably Cambrian, or even Pre-Cambrian.

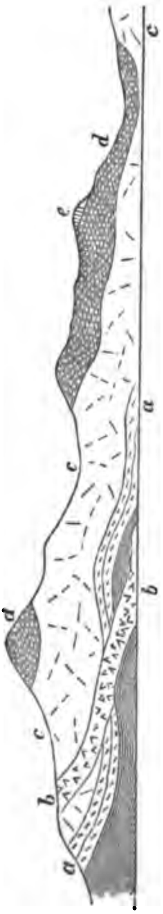


FIG. 131.—Snowdon (Ramsay), mainly composed of igneous rocks of Silurian age. *a*, grits; *b*, eruptive greenstone; *c* and *e*, felspathic rock; *d*, ash, etc.

The Silurian strata for the most part consist of a vast succession of hard and close-grained sandstones, grits, flags, and conglomerates, with shales, slates, limestones, a few schists, and an enormous quantity of erupted and interbedded volcanic rock, both lava and ash. In this respect the Silurian system differs from the Cambrian; for the latter, though greatly metamorphosed, shows little trace of contemporaneous volcanic action. With the Silurian period a time of intense volcanic activity evidently set in, for not only are the rocks penetrated by dykes, but numerous beds of lava and ash are interstratified with aqueous rocks. It is the presence of these hard igneous rocks, the variations of comparatively soft shales with hard sandstones, limestones, and slates, combined with contortion, metamorphism, and faulting, which has caused the Silurian regions to present the most irregular and diversified surface of all the geological systems. This variety has not been caused by the upheavals and outpourings of the volcanic outbursts, but by atmospheric denudation, continued through ages of time, gradually corroding, disintegrating, and removing the softer strata more rapidly than the hard. That this is so is obvious from the fact that, although the amount of eruptive rock is very large, the most rugged and lofty parts of North Wales, Snowdon, the Carnedds, etc., being formed of it, yet it is quite impossible to identify the volcanic vents from which it issued, the present shape of the surface having apparently no relation whatever to the ancient and original surface.

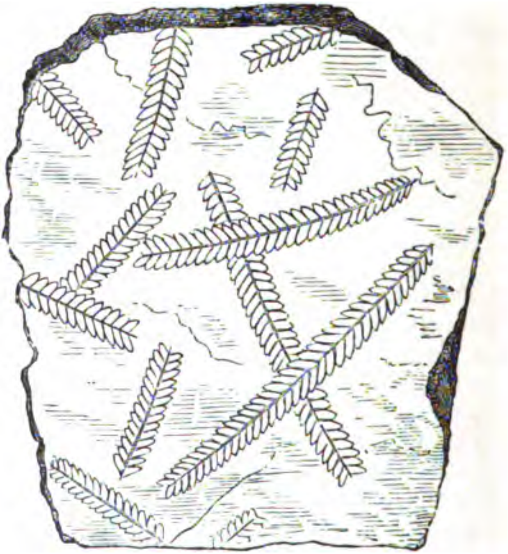


FIG. 132.—Graptolites (*Diplograpsus*).

Picturesque as the Silurian regions are, from the industrial point of view they are the poorest, and support the thinnest population. The hills, where they are not absolutely bare rock, are mainly covered with heather and peat, and are given up, especially in Scotland, to grouse and deer preserved for sport; the valleys here and there are cultivated a little, or at least produce pasturage for sheep, as do the lower slopes of the hills; and a limited amount of employment is provided in mining for metals, especially lead, in slate-quarrying and lime-burning.

Fossils are extremely abundant, especially in the Silurian rocks of Wales. Trilobites reach their greatest development and begin to decline. Brachiopods continue numerous; and members of various other classes, such as Lamellibranchs and Gasteropods, increase very greatly in number. The most characteristic fossil, however, is the *graptolite*, which is not found out of the Silurian system, either above or below.

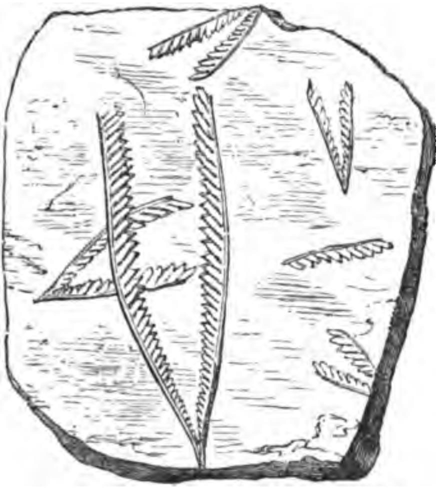


FIG. 133.—Graptolites (*Didymograpsus*).

The Silurian rocks make up a thickness of twenty thousand feet, or nearly four miles. They are divided into upper and lower divisions (the latter sometimes called *Ordovician*), each comprising several series.

The bottom series is the **Arenig**, named from the Arenig Mountains of Merioneth. It is mainly composed of fine black slates, a few flagstones, and interbedded lavas and tuffs, and with the overlying Llandeilo series it forms some of the chief of the hills of Wales, among them Cader Idris. The most noteworthy bed in the Arenig series is a hard quartzose sandstone

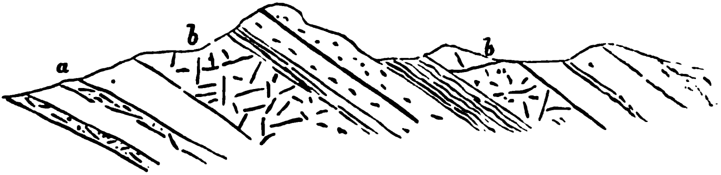


FIG. 134.—Cader Idris. *a*, Lingula flags and Tremadoc slates with igneous rock. *b*, Igneous rock, Arenig and Llandeilo series.

near the bottom. The outcrop of this bed forms an irregular and jagged ridge on the east of the Longmynd, known as the "stiperstones." It extends a distance of ten miles in a south-west direction, and is a remarkably good illustration of the manner in which a comparatively thin bed of hard rock will resist denudation, and make a striking feature in the scenery of a district.

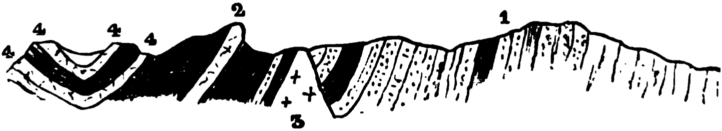


FIG. 135.—1, The Longmynd; 2, stiperstones; 3, eruptive rock; 4, bedded igneous rock.

The **Llandeilo** series is named after a town in Carmarthenshire. There is nothing especially noteworthy in these beds, which are mainly hard shales, sandstones, and inter-bedded lavas. Some of the smaller slate quarries near Snowdon belong to this series. Fossils are fairly abundant, especially *graptolites.* Special trilobites of the genera *Asaphus, Ogygia* and *Calymene* occur, and important genera of brachiopods, such as *Rhynchonella* and *Strophomena,* first appear.

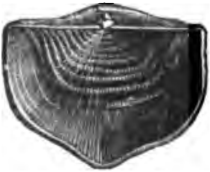


FIG. 136.—Strophomena depressa.

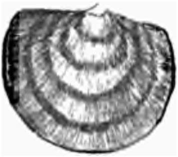


FIG. 137.—Strophomena rugosa.

Caradoc and Bala beds. At Caradoc Hill, in Shropshire, there are yellowish and often calcareous sandstones and sandy shales, and at Bala they pass into slates with a bed of limestone, known as the Bala limestone. In the Snowdon district volcanic rocks are present in large quantity, the summit and much of the hill being composed of them. Fossils are very abundant, especially in the Bala limestone, notably trilobites, which reach their greatest development in this series, no less than 123 species having been collected. The chief genera are *Agnostus, Asaphus, Calymene, Illænus,* and *Phacops,* Lamellibranchs and brachiopods have also largely increased, and corals are becoming very numerous, and include *Favosites* (Figs. 139, 140), *Heliolites*, and *Petraia*. *Cystideans*, a peculiar group of echinoderms, somewhat between encrinites and sea-urchins, entirely confined to the Palæozoic era, are also noteworthy.

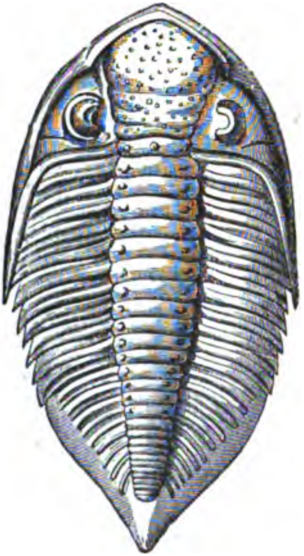


Fig. 138.—Phacops caudatus.

The **Llandovery** series, mainly grits and sandstones, is divided between Upper and Lower Silurian, and stands in an intermediate position between the two, forming what are called "passage beds." The line is drawn at the bottom of a sandstone called the *May Hill sandstone*, which has at its base a conglomerate made up of lower Silurian pebbles, and which is found resting unconformably upon the Cambrian rocks, and upon members of all the lower Silurian series. The sandstones of the upper division are often very full of fossils, and quite calcareous, one of them being known as the *Pentamerus limestone*, from the abundance of a brachiopod called *Pentamerus oblongus*. In places, the Upper Llandovery beds pass upwards into a series of pale blue, green, or purple slates, known as the *Tarannon shales*, and these are followed by—

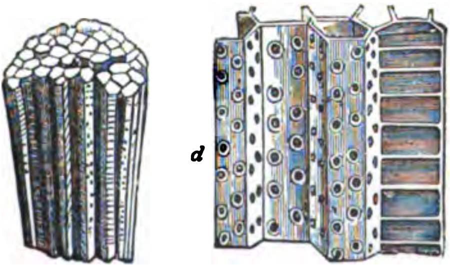


Fig. 139.—*Favosites Gothlandica*: A, cluster of tubes; B, tubes magnified.

The **Wenlock** series. This group consists of a series of shales and slates, some of which are worked for roofing, with an irregular bed of nodular limestone, known as the *Woolhope*, rich in trilobites, below, and a bed of limestone, called the

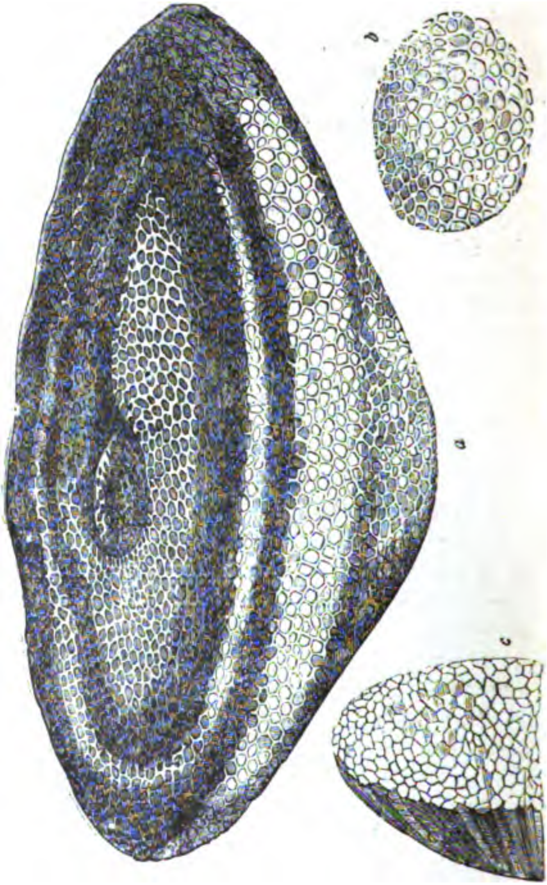


FIG. 140.—*a, Favosites Gothlandica*: *b*, young specimen; *c*, section, showing tubes.

Wenlock limestone, on the top. This latter bed is noteworthy in many ways. It varies very much in thickness, being in some places three hundred feet, and in others absent altogether. It makes a noteworthy ridge of high ground known as Wenlock Edge, inasmuch as it lies between two sets of shaley beds, and the whole are inclined at a considerable angle. It is rather irregular in texture, and not well-suited for building, but it is largely quarried for lime-burning, and for use as a "flux" in the smelting of iron. But to the geologist it is most interesting on account of its great wealth of fossils. It seems to have been a coral bank, and no less than seventy-six species of corals have been obtained from it, among them being *Halysites*, or "chain coral," *Favosites*, *Syringopora*, *Omphyma*, and *Heliolites*. Crinoids are abundant, particularly *Cyathocrinus;* and *Actinocrinus* here makes its first

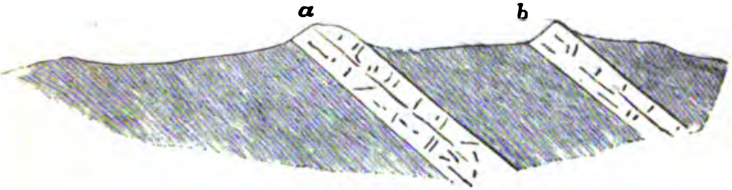


FIG. 141.—*a*, Wenlock limestone, forming Wenlock edge; *b*, Aymestry limestone.

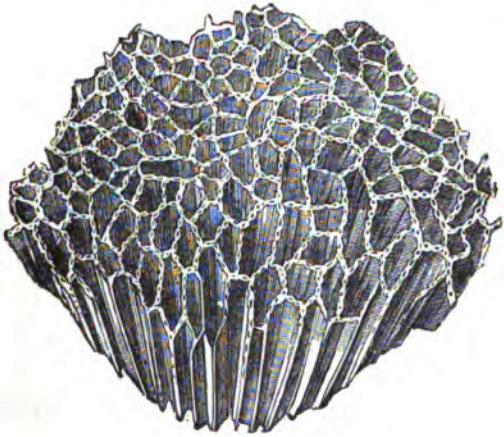


FIG. 142.—Halysites, or "Chain coral."

appearance. Trilobites, though common, are on the wane. *Asaphus*, *ogygia*, and *trinucleus* have disappeared; and their places are taken, among others, by *Calymene*, one species of which, *C. blumenbachii*, is perhaps the best known of the whole order, and is popularly known as the "Dudley locust." Many species show a tendency to develop knobs and tubercles; as, for instance, the *Encrinurus*, or "strawberry-headed" trilobite. A crustacean order, the *Eurypteridæ*, is now on the increase. These are creatures armoured, like the trilobites, on the back and head, but with longer bodies, and jointed appendages round their mouths, which apparently assisted them in locomotion as well as for feeding. They are exclusively Palæozoic. The chief genera found here are *Eurypterus* (Fig. 147) and *Pterygotus* (Fig. 146).

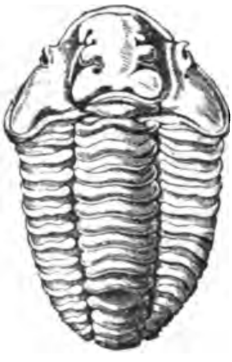


FIG. 143.—*Calymene blumenbachii* (the "Dudley locust").

The **Ludlow** series, like the preceding, also consists of shales, with a thick bed of limestone, known as the Ludlow or Aymestry limestone, in the middle. These alternations of shales and limestones which mark the latter portion of the Silurian age, indicate an oscillating movement of the crust, producing at one time shallow and muddy water, and at another time water which was clear and comparatively deep. During the clear-water periods, the corals and other limestone-forming organisms returned and flourished, and their remains now form the beds of limestone. In the Ludlow limestone trilobites are not nearly so abundant as in the older limestones, but *Eurypterids* and *Asterids* (star-fishes) are more numerous. Brachiopods are abundant, especially *Rhynchonella* and *Pentamerus*, the *Pentamerus Knightii* being especially characteristic of the Ludlow beds. The limestone is dark and earthy, very inconstant, and often concretionary, and forms a well-marked escarpment parallel to Wenlock Edge. It is burnt for lime when pure, and for cement when earthy. In several instances landslips have been caused by the slipping of the Ludlow limestone over the soft shale below it. This underlying shale has yielded a few remains of ganoid fishes, and a still larger series has been collected from the Ludlow "bone bed" above the limestone. This bed, which is only a few inches in thickness, is almost entirely made up of the bones, teeth, scales, bony plates and spines of *Cepalaspis*, *Pteraspis*, *Scaphaspis*, etc., and crustaceans. These Ludlow fishes are the earliest known vertebrate remains.

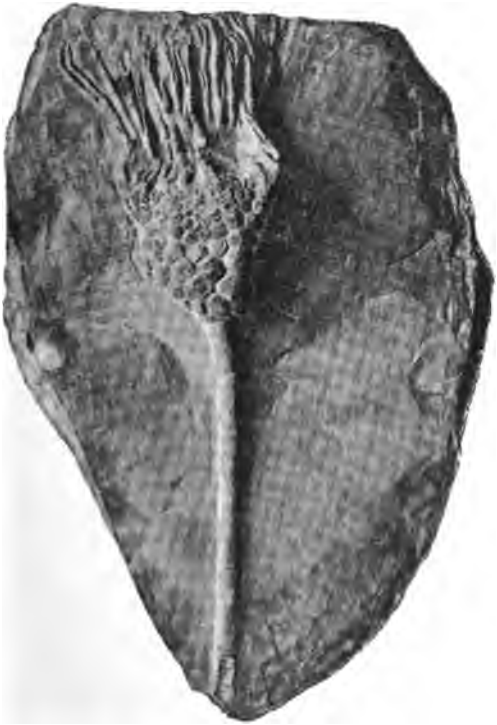


FIG. 144.—*Glyptocrinus expansus.* Wenlock limestone, Dudley. (Jermyn Street Museum.)

The upper portion of the Ludlow series is composed of flaggy sandstones, called the *Tilestones.* As far as their fossils are concerned they are Silurian, but in mineral character they more nearly resemble the rocks of the next system, and may be evidently regarded as passage beds.

None of the other Silurian areas of the British Islands exhibit so complete a series of strata as Wales and the West of England, or so extensive an assemblage of fossils. In the other localities the volcanic products are as a rule in still greater force, and there is more intense metamorphism, so that it is not possible in all cases to say what are their exact equivalents in the typical area. The Silurian districts of

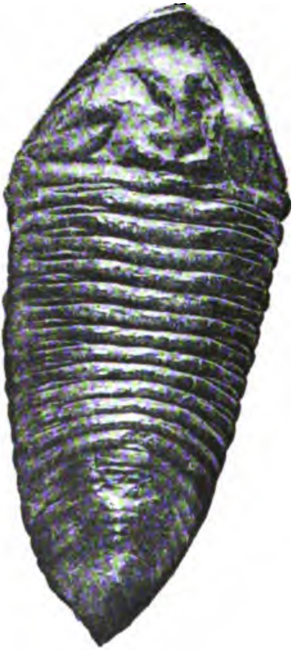


FIG. 145.—*Homalonotus delphinocephalus*. Wenlock limestone, Dudley. (Jermyn Street Museum.) A photograph of the identical specimen figured by Murchison in "Siluria," and by the Palæontographical Society.

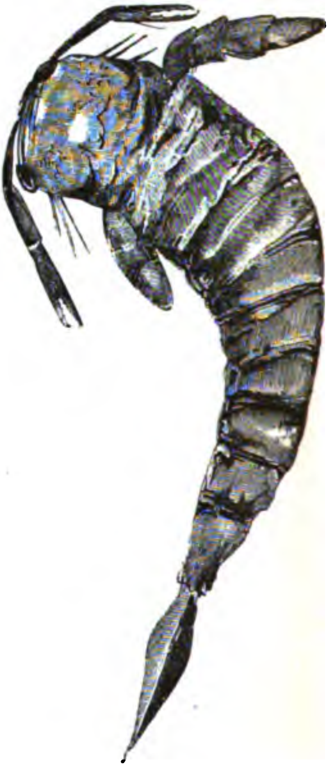


FIG. 146.—*Pterygotus acuminatus* (eurypterid).

Ireland rise like a series of rocky islands from the more level carboniferous rocks which spread over the greater part of the island, and with igneous rocks constitute all the wild, picturesque, but generally barren regions of the south-west, west, and north-west of the island.

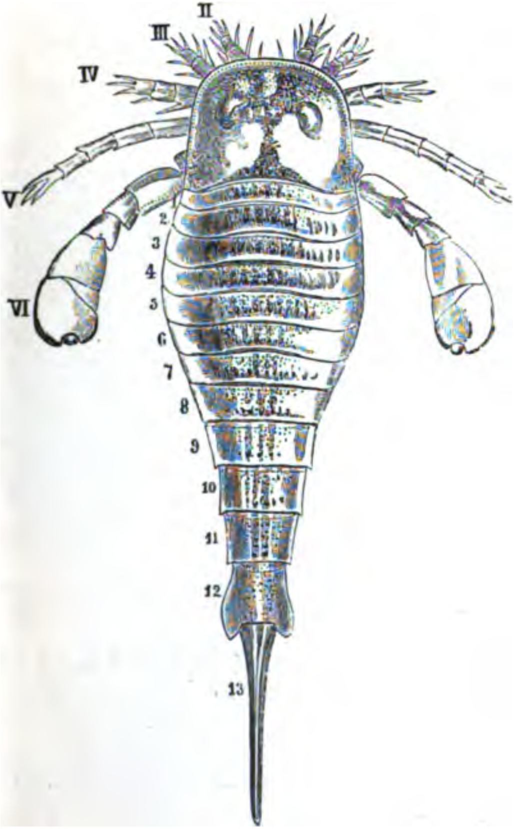


FIG. 147.—*Eurypterus*.
II–VI, jointed appendages for taking food and locomotion; 1 12, segments; 13, tail-piece, or *telson*.

Silurian strata occur in various parts of the world, but, though they contain many fossils, as a rule the genera but not the species are identical with those of England, the difference of course being greater when the strata are most distant. Even, however, in the case of America and Australia, some of the species are the same. In mineral and physical character the various localities differ widely. In France they are more metamorphosed, contorted, and faulted than with us, while in Russia there are Silurian strata, consisting mainly of loose sands and soft clays. In Bohemia the series of Archæan, Cambrian, and Silurian rocks has been carefully worked out by M. Barrande, who has arranged them in eight stages, denoted by letters.

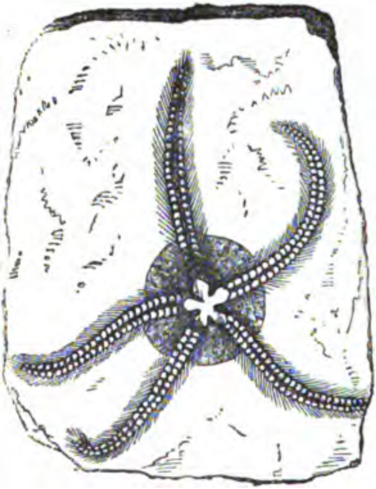


FIG. 148.—*Protaster Miltoni* (a star-fish) from the Upper Ludlow.

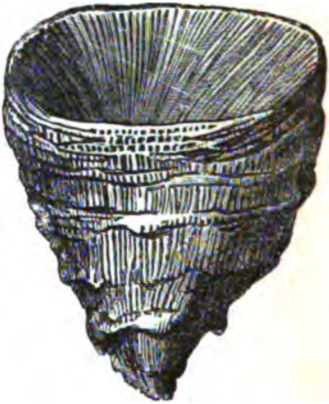


FIG. 149.—*Omphyma* Silurian coral.

Third Fauna	Upper Silurian	Étage H. ,, G. ,, F. ,, E.
Second Fauna	Lower Silurian	,, D.
Primordial	Cambrian	,, C.
Azoic	Pre-Cambrian	,, B. ,, A.

A very complete series of the Silurian strata, in an abbreviated form, is exhibited near Christiana, in Norway; and very fossiliferous strata occur in the Baltic islands of Gothland and Oesel.

In North America there is a large Silurian area near the Great Lakes. The strata here are of great thickness, and are grouped into numerous divisions, bearing local names; but though the upper and lower divisions are well defined, the subordinate divisions cannot be correlated with those of Europe. The rich copper mines of Lake Superior occur in these rocks.

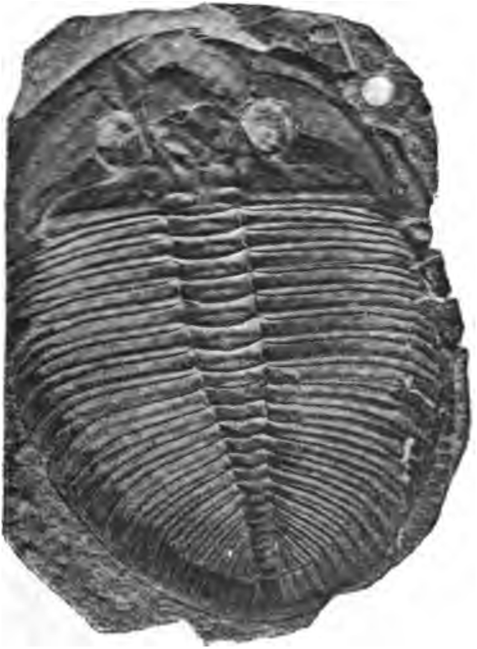
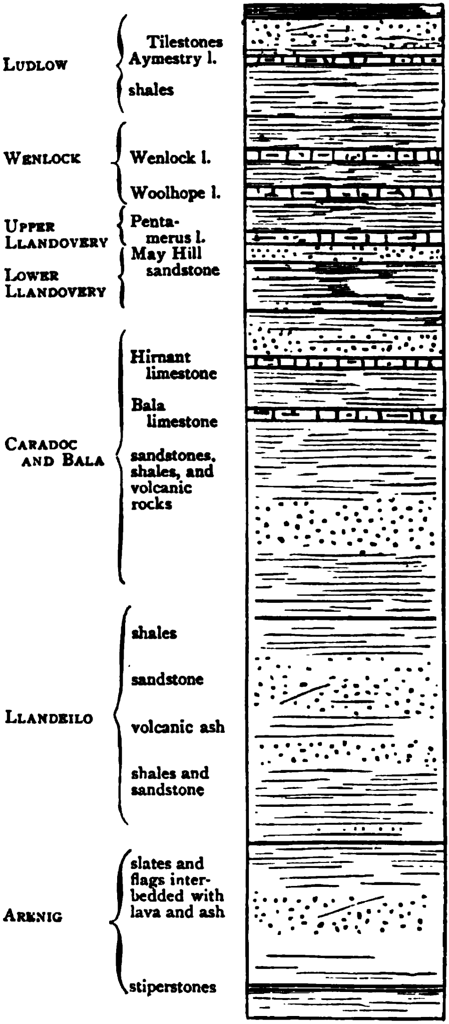


FIG 150.—*Ogygia Buchii.* Landeilo Flags, Builth. (Jermyn Street Museum.) The type specimen, figured in "Decades of Geographical Surveys" (vol. ii. plate 6).

The Silurian schists and slates frequently contain in their joints and fissures metallic ores, which are largely worked. In addition to lead, zinc, copper, and silver, gold is found more or less in nearly all localities. The precious metal has been obtained in small quantities at various times and in different places in Wales, Scotland, and Ireland, and of late extensive workings have been opened near Dolgelly, though it is doubtful whether they will ultimately pay. The Australian gold is derived from quartz veins traversing lower Silurian rocks.

THE SILURIAN SYSTEM.

Scale: 1 inch = 4,000 feet; the whole embracing about 22,000 feet.



Fishes: cephalaspis, pteraspis, scaphaspis; eurypterids; pentamerus, rhynchonella.

Protaster, etc.

Corals: halysites, favosites, syringopora, omphyma.

eurypterus, pterygotus, calymene, homalonotus, cyathocrinus, actinocrinus, glyptocrinus.

pentamerus.

Trilobites very abundant:—Agnostus, asaphus, calymene, homalonotus, illænus, phacops.

Corals:—favosites, heliolites, petraia.

Cystideans.

Graptolites,

asaphus, ogygia, calymene,

rhynchonella, strophomena.

ECONOMIC PRODUCTS, mainly limestones; lead, zinc, copper, silver.

FIG. 151.

Summary.—The Silurian system was established and described by Sir R. Murchison in 1838. It forms the most rugged and picturesque, but at the same time the most barren, parts of the British Isles. Its strata are very diversified, largely intermingled with igneous rocks, and highly fossiliferous, trilobites and brachiopods being especially abundant, and graptolites especially characteristic. The system may be tabulated as on the preceding page.

Silurian rocks occur in North America and Australia, with fossils of the same genera, but as a rule of different species. In France the Silurian strata are more altered, and in Russia much less altered, than in the British Isles. They also occur in Bohemia, Norway, etc. Silurian strata are rich in mineral ores.

QUESTIONS.

1. In what British localities are Silurian strata found? Why is Wales considered the "typical locality"?
2. To what is the rugged character of the Silurian areas due?
3. Mention any proofs that the Silurian rocks have suffered extensive denudation.
4. What fossil groups are especially characteristic? Describe them.
5. Give an account of the Stiperstones, Pentamerus limestone, Tilestones, the Bone Bed, the Wenlock limestone, and place them in chronological order.
6. What proofs are there of alternating physical conditions in this period?
7. Give an account of the following fossils: halysites, calymene, pentamerus, pterygotus, rhynchonella; state to what sub-kingdoms they respectively belong, and in what strata they would be most readily found.
8. Describe, with a diagram, the geological structure of Snowdon.

CHAPTER XXI.

THE DEVONIAN SYSTEM.

It is comparatively easy to recognize rocks of the Silurian system, owing to the abundance and characteristic nature of their fossils. The Carboniferous is also a well-defined system, occupying a considerable space in the British Isles, and from its physical characters and fossils readily recognized. All the rocks which are apparently more recent than the Silurian and older than the Carboniferous are included in the Devonian system. Such rocks occur in numerous localities all over

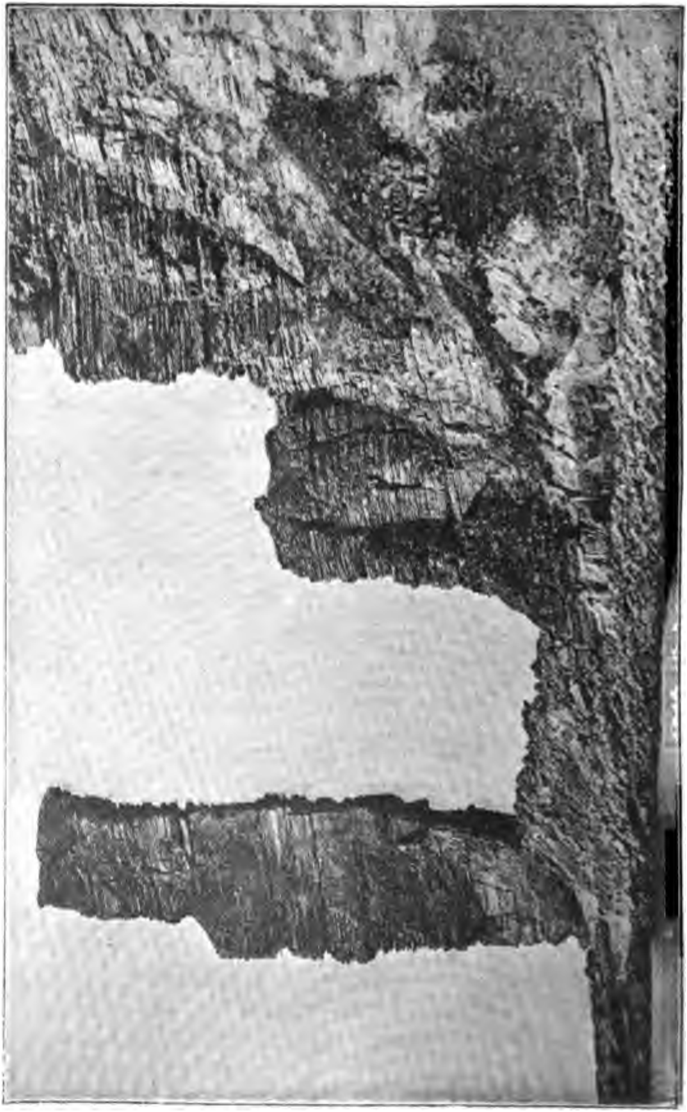


FIG. 152.—The "Old Man" of Hoy, Orkney. (Wilson.) A detached column of Old Red Sandstone, 600 feet high, resting unconformably on a base of Silurian rock.

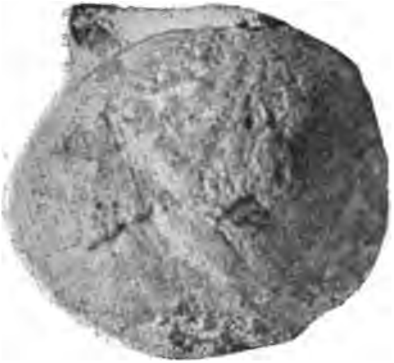


Fig. 153.—*Stringocepholus*. Internal cast. Mid. Devon. (Jermyn Street Museum.)

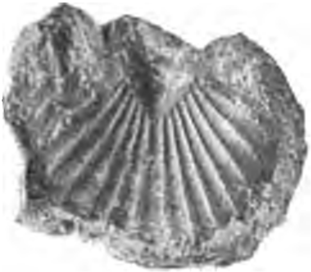


Fig. 154.—Tail of *Bronteus flabellifer*. Mid. Devon. (Jermyn Street Museum.)

the British Isles, sometimes resting, generally unconformably, upon older rocks, and in other cases brought against both older and more recent rocks by faults. Nearly the whole of Cornwall and much of Devonshire is occupied by these rocks; but these are different from all the rest, inasmuch as, while they exhibit all the appearance of having been deposited in the sea, the rest are probably wholly, or almost wholly, fresh-water deposits. In all probability the volcanic disturbances of the Silurian period resulted in an irregular upheaval or disturbance of the surface, leaving some parts elevated and others depressed, and thus forming basins which were gradually filled with fresh water, and became receptacles for the waste of the surrounding land. A great lake of this kind, to which the name of Lake Orcadie has been given by Sir A. Geikie, existed in what is now the north of Scotland, and is represented at present by the red sandstones of Orkney and of the shores and neighbourhood of the Moray Firth; another, called Lake Caledonia, received the deposits which on the north are brought against the Highland rocks by a great east and west fault, and which flank the southern uplands on the south. Other similar deposits may be seen in the Cheviot district, and in Herefordshire and the south-east of Wales. All these deposits are generally included in the name of Old Red Sandstone—*red* because of their colour, and *old* because there are other red rocks which are more recent. The marine rocks of Devon and Cornwall, on the other hand, are always spoken of as "Devonian," though this name is sometimes applied to the red rocks as well.

The Devonian rocks of the south can nowhere be seen to rest upon the Silurian rocks; and it is thought quite possible that their bottom portion may really have been deposited contemporaneously with the upper Silurian in other localities, while their highest beds may in point of time belong to the Carboniferous system. The system can be divided into three well-marked divisions—the Lower Devonian, consisting mainly of shales; the Middle, of limestones; and the Upper, of sandstones. The limestones are well seen in the neighbourhood of Torquay; but they are very difficult to follow and co-ordinate, as they are much disturbed and contorted, broken by faults, and even, in some cases, apparently reversed. These limestones are very fossiliferous, and are particularly rich in corals, containing not less than fifty species, all new, though mostly of Silurian genera, the most noticeable being *Cyathophyllum* and *Favosites*. The corals were apparently, for the most part, deep-water species, though reef-builders were not absent. These South Devon limestones, or "marbles," when polished, exhibit these corals in beautiful detail.

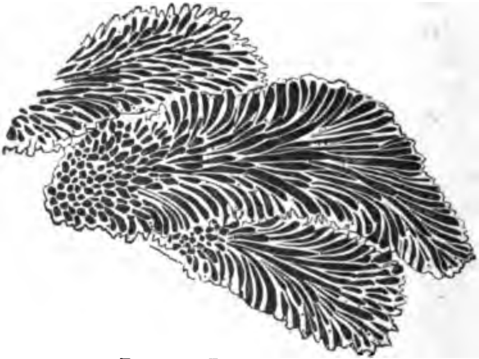


FIG. 155.—*Favosites cervicornis*.

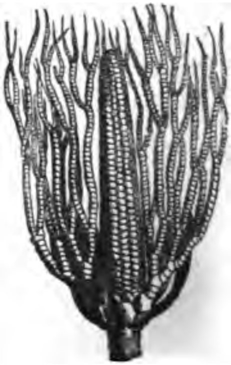


FIG. 156.—*Taxocrinus*, a Devonian encrinite.

Crinoids are also abundant in the Devonian rocks, though many Silurian forms now die out and are succeeded by genera which continue into the Carboniferous period. *Cyathocrinus* is one of the best known. Brachiopods are still very abundant, being represented by more than a hundred species, of which twenty-two belong to the genus *Rhynchonella*, and nineteen to *Spirifera*. These latter, with *Atrypa* and *Pentamerus*, are common to the Silurian system. *Chonetes* is new, and is prolonged into the Carboniferous; while *Uncites* is confined to the Devonian rocks.

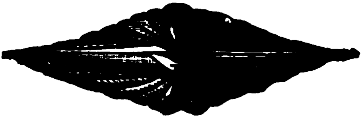


Fig. 157.—*Spirifera speciosa.*

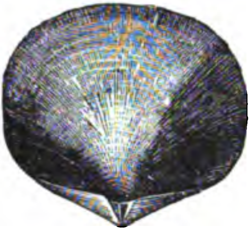


Fig. 158.—*Orthis striatula.*

Two Devonian Brachiopods.

Among the Lamellibranchs, *Aviculopecten* and *Pterinea* deserve mention, and *Megalodon* is characteristic.

Only eleven species of Trilobite are found. Five belong to the genus *Phacops;* but *Bronteus* and *Homalonotus* should also be noticed. Gasteropods are both numerous and important, notably *Euomphalus* and *Murchisonia* (Fig. 161).

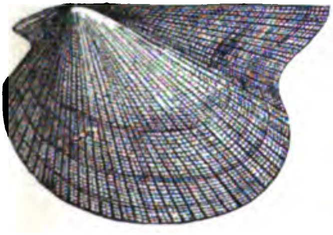


Fig. 159.—*Pterinea.*

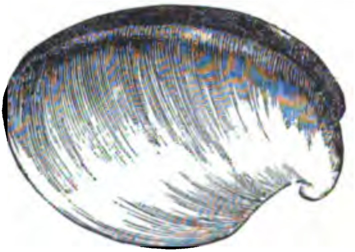


Fig. 160.—*Megalodon.*

Two Devonian Lamellibranchs.

Of cephalopods, the genus *Goniatites* is important, supplying eighteen species, and it is also interesting as the precursor of the Ammonites, which became very abundant later on. *Nautilus*, *Orthoceras*, and *Clymenia* also require mention, the latter being confined to the Devonian period, and very characteristic. All the foregoing are marine fossils, and are almost restricted, in the British Isles, to the rocks of Devon and Cornwall.

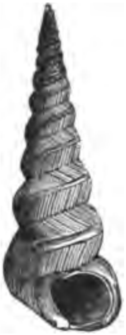


Fig. 161.—*Murchisonia gracilis.*

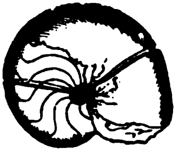


Fig. 162.—*Goniatite (retrorsus).*

The other rocks of Devonian age, more commonly called Old Red Sandstone, are very different to the foregoing. They consist, for the most part, of enormous beds of conglomerate, containing specimens of nearly every kind of older rock, of red or yellow sandstones and marls, a few interbedded limestones, and, at places, of layers of interbedded volcanic ash and lava of immense thickness. Several of the minor hill ranges of Scotland, the Sidlaws, Ochills, and Pentlands, and great part of the Cheviots, are due to these volcanic rocks. The red colour of the sandstones is caused by the presence of iron oxides, which cement the grains of sand together, the grains themselves being generally colourless silica. This is considered strong evidence that the rocks were laid down in fresh-water lakes, where ferruginous matter is much more common than in the sea, and it also serves to explain the singular scarcity of fossils in most of the beds, as the presence of iron compounds in water is very unfavourable to life. Fossils, however, are not entirely wanting. From calcareous nodules in thin clays which are intercalated in the thick red sandstones of the Moray Firth, Hugh Miller, when a working stonemason, was the first to collect a series of fish remains and impressions of very great interest. A few fish remains are found in the upper Silurian rocks, but they are very fragmentary and of few species; but these Old Red Sandstone fishes are both well preserved and numerous. They are nearly all ganoids, or allied to them; and the appearance of some of them, clad in a strong defensive armour of enamelled bony plates, is so extraordinary and so unlike that of an ordinary fish, that they were for a long time considered to be crustaceans. The most noteworthy of them are *Cephalaspis*, or "buckler-headed;" *Pteraspis*, or "buckler-winged;" and *Coccosteus*, or "berry-boned," so called on account of the knobs with which it was decorated. Other ganoids, more nearly resembling modern fishes, and found chiefly in the Upper Old Red, are *Osteolepis*, or "bone-scale;" *Holoptychius*, or "all-wrinkled," and *Glyptolepis*, or "carved-scale." Other fishes, allied to sharks and to the mudfish of Africa and South America, also occur; and many others, in all 120 species, so that we have fairly arrived at a period in the world's history when fishes are abundant. These Palæozoic fishes all agree in having the backbone continued into one of the divisions of the tail fin, instead of stopping short, as it does in most fishes with which we are familiar. This peculiarity gives the tails an unsymmetrical appearance ("heterocercal"), which is easily recognized. It may be seen in the shark and sturgeon of the present day, which may be regarded as the survivors of the old and almost extinct Palæozoic type. As these old Devonian fishes have been long extinct, it is impossible for us to be quite sure, but it seems most probable that they frequented fresh water, since most of the modern fishes to which they are related, such as the sturgeon and various "mud fishes," the Polypterus of the Nile, and others, are limited to fresh water.

With abundant fossil fishes we have, for the first time, abundant and perfect land plants. Some of the fronds, four or five feet long, of a fern called *Palæopteris* (Fig. 167), together with many others, have been found in Devonian sandstone in Ireland. Plants are also found allied to our modern club-mosses and horsetails, such as *Calamites*, which in the next system assume a position of great importance. In Canada still higher forms of vegetation are represented by conifers and by a piece of dicotyledonous wood. In the same locality we have the first evidence of insect life, in the discovery of various wings, somewhat like those of our dragon-flies.

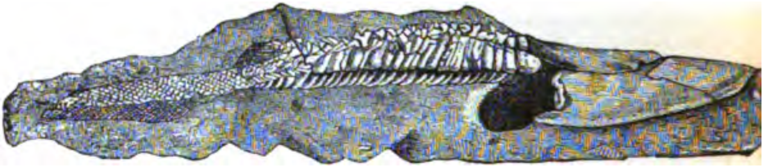


FIG. 163.- *Cephalaspis.*

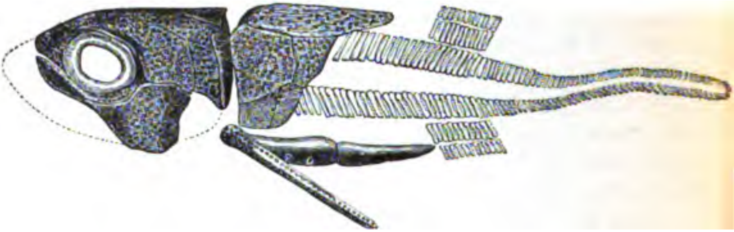


FIG. 164.—*Coccosteus.*

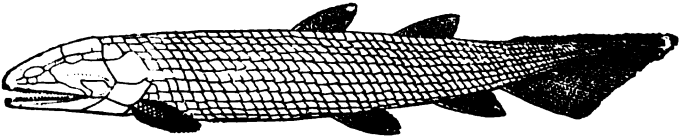


FIG. 165.—*Osteolepis.*

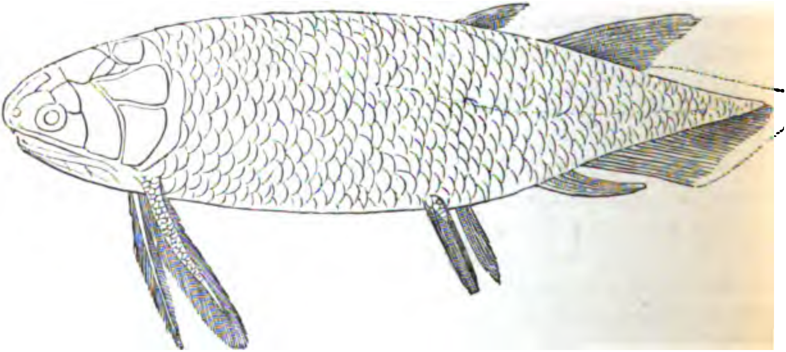


FIG. 166.—*Holoptychius.*

DEVONIAN FISHES.

These Old Red fishes and land plants are so different from the Devonian corals and mollusca that it is evident that some physical barrier must at that time have existed somewhere in the line of the Bristol Channel. North of that line we have strata of the fresh-water type; south of it, marine beds. Similar marine strata, passing upwards conformably into the Carboniferous, are found in north-east France, in Belgium, and in the Rhine basin; and rocks of the same type occur in Normandy, Brittany, and the Asturias Mountains. In Ireland, where there are numerous inliers exposed by the denudation of the overlying Carboniferous rocks, the type is mixed; the lower beds, which rest unconformably on the Silurian, contain ganoid fishes, like the Old Red; while the upper beds, which pass conformably into the lower Carboniferous, contain brachiopods and other marine fossils. It is the same in Russia, where sandstones contain Old Red fishes, and intercalated limestones marine shells.

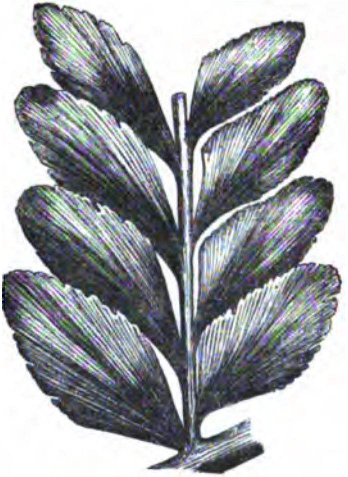


FIG. 167.—*Palæopteris.*

The Old Red system in Britain is divided into upper and lower divisions, unconformable to each other; the lower, in some instances, as in South Wales, passing conformably downwards into the Ludlow beds, and the upper more frequently, as in Dean Forest, the Mendips, and other localities, passing upwards into the lower limestones and shales of the Carboniferous system. The conglomerates of the Old Red are very massive and interesting, both from the variety of pebbles which they contain, and from the fact that it has been thought that some of the pebbles exhibit signs of glaciation. This is particularly the case with a red conglomerate which in broken patches fringes the Lake Country and passes conformably upwards into the mountain limestone, and its position on the outskirts of a hilly region, where glacial *débris* would naturally accumulate, favours the idea. Another noticeable series is the "cornstones." These are marl-stones with concretions of limestone varying in size from small pebbles to thick and continuous masses. They occur at the base of the Old Red in Herefordshire, and at other horizons.

Strata of Devonian age occur in America on both flanks of the Alleghanies. Like the Irish and Russian systems, they contain both types of fossils; but they are particularly noteworthy as being the source of immense supplies of petroleum, which is generally obtained from them by artesian borings. It is thought that this petroleum has distilled, not from vegetables, but from decomposing animal matter in the limestones, such as fishes, crustaceans, and mollusca, whose hard parts are embedded in it in great abundance. This is also the source of the deposits of bitumen, with which also some of the shells are filled.

As regards other useful products from this system, the sandstones make excellent building material. The volcanic rocks are used for road-mending, its flags for paving, its limestones for lime-making, building, and decorative work. Valuable ores of copper and tin ramify in veins and lodes through the slates or "killas" of the lower division in Cornwall. Iron, lead, and other metals are also obtained.

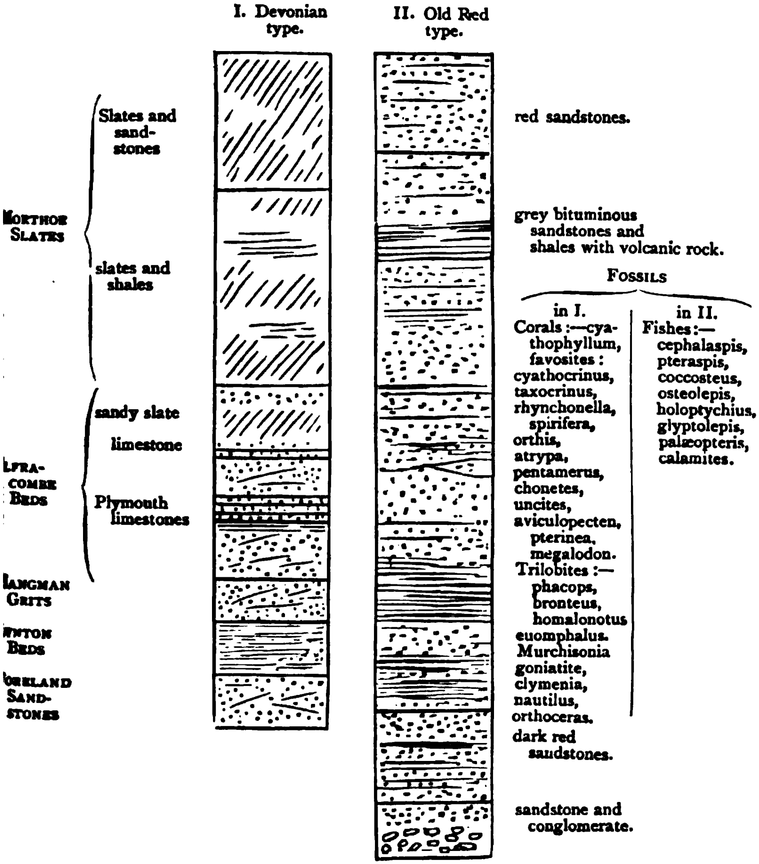
SUMMARY.—The Devonian system may be defined as comprising all the strata which lie between the Silurian and Carboniferous systems. It consists, in the British Isles, of fresh-water strata for the most part, with marine beds in Devonshire and Cornwall (see p. 243).

QUESTIONS.

1. Contrast the rocks of this period, which are found in Herefordshire, with those found in Cornwall. To what geographical conditions may the difference be attributed?
2. Give a brief account of the four chief British Old Red localities, and describe the conditions under which these red strata were formed.
3. Describe the Devonshire marbles and their fossils.
4. Mention four Devonian fossils belonging to four different classes.
5. Give an account of the Old Red fishes, their special peculiarities, and their modern representatives.

THE DEVONIAN SYSTEM

Scale: 1 inch = 4,000 feet.



Economic Products:—Limestones for building and decoration,
igneous rock for road-making,
copper, iron, lead.

Fig. 168.

6. What remains of land plants have been found in the Old Red rocks? Describe them, and give the localities.
7. Under what conditions do rocks of this period occur in Ireland?
8. Describe the Old Red Conglomerate of the Lake Country, and discuss its origin.
9. What useful products are obtained from this system?

CHAPTER XXII.

THE CARBONIFEROUS SYSTEM.

THE word "carboniferous" means *carbon-bearing* or *coal-bearing*, and this system is so called because practically all our coal is got from it. Other systems yield coal, but none so much or so generally as this. The rocks of the carboniferous system are very noticeable and well-marked, and impart very distinctive physical features to the areas where they occur. Its fossils are both abundant and interesting, and the commercial value of its productions is very great.

The lowest beds are often quite conformable with the underlying Old Red Sandstone, the marls and sandstones of the latter system passing in some places abruptly, in others with intervening shales and sandstones, into the thick slabs of massive limestone known as the *Carboniferous Limestone.* In South Wales the "passage beds,"

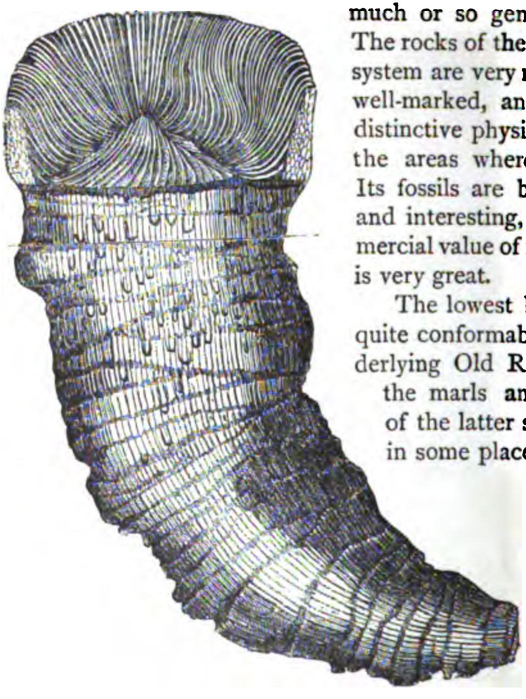


FIG. 169.—*Clisiophyllum,* a carboniferous limestone coral.

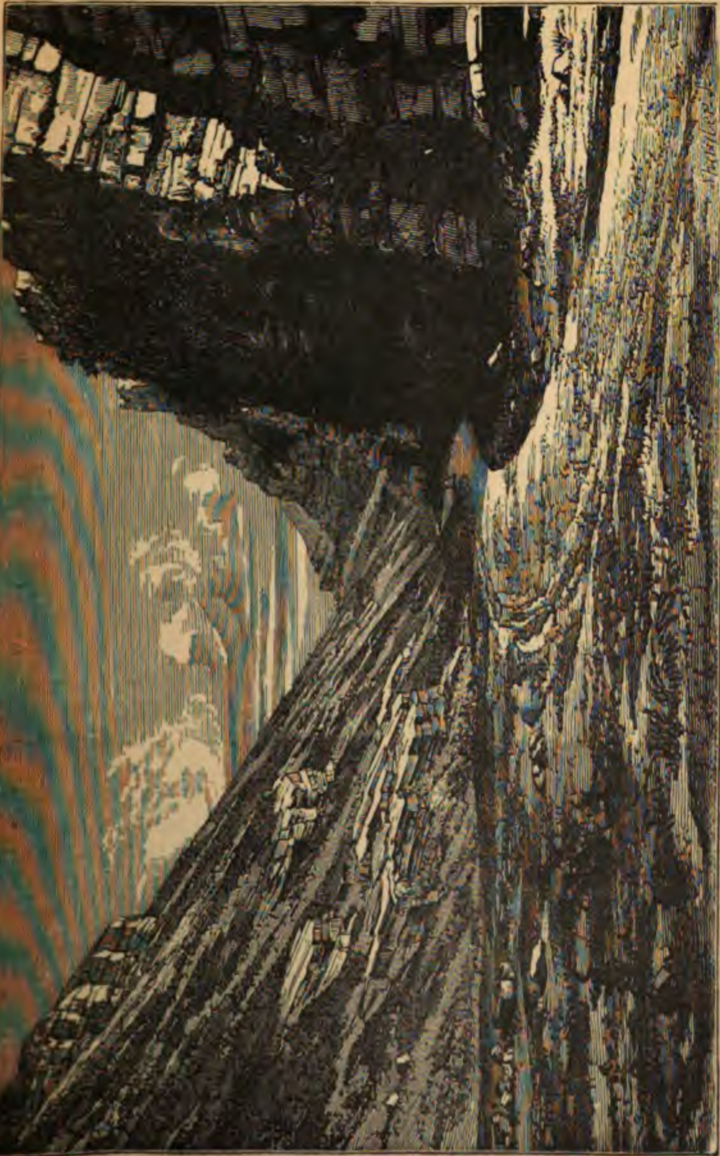


FIG. 170.—Cheddar Cliffs. Carboniferous or Mountain Limestone.

known as the *Lower Limestone Shales*, consist of sandstones, clays, and shales, often sandy, with thin limestones in the upper part, and may be seen well displayed in the valley of the Avon, Dean Forest, and the Mendips, where they vary in thickness from two hundred to five hundred feet.

The Carboniferous Limestone, which is formed mainly of molluscous shells, corals, and encrinites, forms some of our most striking scenery, on account of the vertical cliffs or escarpments formed by the denudation of the great horizontal beds. Fine specimens of these escarpments may be seen in the Cheddar cliffs in the Mendips, in the neighbourhood of Buxton and Matlock in Derbyshire, and in the dales and among the hills of the north-west of Yorkshire. In the latter locality the limestone, with a conglomeratic base, rests unconformably upon the upturned edges of the Silurian slates, and is practically undivided from top to bottom. It here forms grand precipices along the sides of the valleys and round the bases of the hills, and from the important geographical part it plays in this region it has obtained the name of "Mountain" limestone. It contains veins of galena, or lead sulphide, and of zinc carbonate, which are worked, especially the former, very largely in the north; and in Derbyshire it is interstratified with beds of igneous rock known locally as "Toadstone," a fact which bears witness to contemporaneous and probably submarine volcanic outbursts. Beds of hæmatite also occur in Furness, and are largely worked, and have given birth to the important town of Barrow.

As the limestone is followed northward it shows a marked tendency to develop thin beds of shale and sandstone, first in its upper portion, then at the base, and finally throughout its whole thickness; so that in Scotland the limestone is practically absent altogether, and is represented by beds of shale and sandstone, with layers of coal and occasional beds of ironstone. In Yorkshire the shales, sandstones, and thin limestones of the upper portion are known as the "Yoredale" beds, from the Ure valley, where they are well displayed. Further north the lower beds, which really correspond to the Lower Limestone Shales already mentioned, are called "Tuedian" beds, from their large occurrence in the Tweed basin.

Such changes as this in masses of rock when they are followed across the country are quite common, and are accounted for by the different local conditions which prevailed during their deposition. In this particular case it is evident that, while comparatively deep and clear sea with corals, shells, and other limestone-forming organisms existed in Derbyshire and Yorkshire, there was a coast-line with shallow water to the northward, where the *débris* of the land was brought into the sea, and beds of mud and sand were thrown down. In process of time the water shallowed more and more, and the sediment intruded itself over the limestone, and formed the Yoredale beds. In the north the occasional beds of coal tell us that sometimes the water was completely filled up, and dry land formed.

A large portion of the centre of Ireland consists of this carboniferous limestone, which in some localities is coloured, and forms an ornamental stone, as the "black marble" of Kilkenny and the "red marble" of Cork.

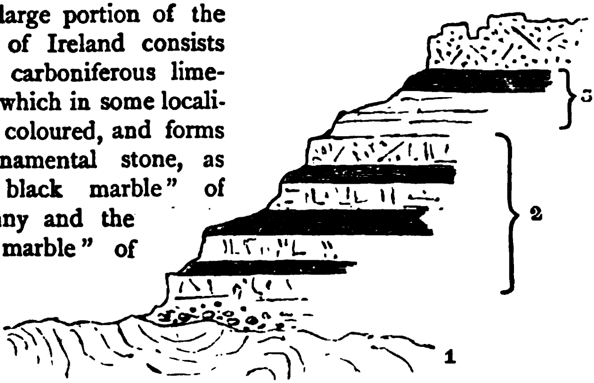


FIG. 171.—Section of one of the hills of the West Riding of Yorkshire, *e.g.* Ingleborough. 1, Silurian; 2, mountain limestone, uncomformable to Silurian, and conglomeratic at base; 3, Yoredales; 4, millstone grit forming the summit.

At last, even in the south, the sea appears either to have been nearly filled up, or to have been shallowed by upheaval, and then an enormous quantity of coarse, angular sand was thrown over it. This now forms a rough sandstone, called the **Millstone Grit**, so named because of its suitability for millstones. It seems to be the waste derived from the disintegration and denudation of a great tract of granite, and was probably brought down from the Scandinavian region by great rivers. It consists of coarse angular grains of sand; partly rolled pebbles of milky quartz, no doubt derived from veins; pieces of felspar, often now quite soft and decomposed; and mica, the latter sometimes in sufficient quantity to cause it to split into thin sheets, though generally the beds are remarkably thick and massive. In the north of Yorkshire outlying masses of it form the summits of the hills, and it spreads over much of the high ground forming the "moors," a barren region covered with peat and heather, and given up to grouse. It contains here and there shales and thin coals. If carefully selected it makes an excellent building material for rough or heavy work.

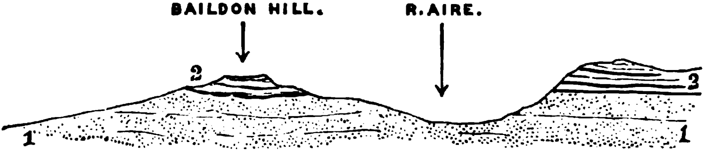


FIG. 172.—Baildon Hill, near Bradford, Yorkshire. An Outlier of lower coal measures (2) resting on millstone grit (1).

The millstone grit gradually, in its upper portions, gets finer and finer and more shaley, until we reach a series of beds consisting of dark shales and fine sandstones, with here and there beds of coal and ironstone. These are the **Coal Measures** which are of such great commercial importance. They vary in thickness from three thousand feet in Northumberland to ten thousand feet in South Wales. The coal-beds occur at various levels in this great pile of strata, and vary in thickness from an inch to several yards; those of average quality which are more than two feet thick being workable. The beds of coal lie in apparently flat layers among the other rocks, but, if followed far, they are found to change in character. They become thinner, and finally die out. Sometimes they split up into two or more thinner layers with intervening shale, and sometimes they became too impure to be worth anything. Consequently it is not possible to recognize the same bed in areas a few miles apart. The coals vary much in quality. If very pure, they contain only two or three per cent. of inorganic or mineral matter; but the more impure qualities may contain twenty or thirty per cent. They vary also much in other ways. Some, such as ordinary household coal, give off much gas and flame freely; others, such as anthracite, burn quietly and with great heat, but with little or no smoke, Some are soft and blacken the fingers; others, like cannel coal break with a smooth clean fracture. Iron pyrites is often present, and is sometimes the cause of spontaneous combustion and other serious mishaps. The pyrites becomes oxidized when moisture is present, and evolves sufficient heat to set fire to the coal. It should be borne in mind that even in the coal measures the beds of coal are relatively thin and far between. On the average they do not form more than from one to two per cent. of the whole thickness of the measures.

As regards the origin of coal, there is no doubt whatever that it has once been vegetable matter. Sometimes, though not often, distinct traces of its vegetable origin can be detected in it, either in the form of woody tissue, or in the spores and spore-cases of ferns and similar plants. Nearly every bed of coal is observed to rest directly on a bed of hard clay, called the *underclay*. In this underclay it is common to find the fossilized roots, large and small, of various plants. Generally, the trunk seems to be cut off just where it enters the coal, but sometimes it stands upright through the coal and extends into the shales above. The shale immediately over the coal bed is often one mass of impressions of fern fronds and leaves of plants more or less fragmentary. The chemical composition

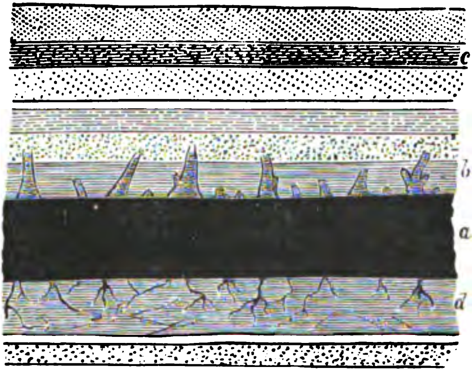


Fig. 173.—Section showing Coal Seam. *a*, coal seam; *d*, underclay with stigmaria and other roots; *b*, *c*, shale and sandstone forming roof, containing fossil stems, leaves, etc.

of the coal, moreover, is just what would be expected from greatly altered vegetable matter. Wood, bark, leaves, and seeds of plants consist of carbon, hydrogen, and oxygen with more or less nitrogen, and a small quantity of mineral matter. Disregarding for the present all but the first three, we find in one hundred parts of average vegetable matter fifty of carbon, six of hydrogen, and forty-four of oxygen. When this vegetable matter dies, decomposes, and rots away, the oxygen unites with some of the hydrogen to form water, and with some of the carbon to form carbonic acid. The nitrogen present, also chiefly unites with some of the hydrogen and forms ammonia. These changes take place at the surface, and would in time, with the help of atmospheric agencies, completely destroy all traces of the original material, but in the case of the coal this final result has been prevented by its burial and consequent protection from the atmosphere. Under these new conditions, aided by pressure and possibly by a certain quantity of heat derived from the earth's interior, various combinations of carbon and hydrogen have been formed, and have passed off by infiltration through the surrounding strata. These hydrocarbons often exist in such quantity in the shales of the coal measures as to make it commercially profitable to distil them for illuminating purposes. Thus step by step everything is gradually removed, till little is left except the mineral matter and a large residue of carbon, and the completeness with which the process has taken place determines the quality of the coal. The following table shows how, as the wood changes into coal, the relative amount of carbon becomes greater and greater. In the case of anthracite the change has been carried almost to the end; and the fact that anthracite is most abundant in the more disturbed areas, renders it probable that in this case, at any rate, heat is required. Graphite, which is almost pure carbon without any hydrogen or oxygen, is perhaps the final result of the series of changes.

	Percentage of carbon.	Percentage of hydrogen.	Percentage of oxygen.
Wood	50	6	44
Peat	60	6	34
Lignite	68	5	27
Coal	85	4	11
Anthracite	94	3	3

Various names are applied to coals, some descriptive, others topographical. *Cannel* (from "candle") *coal* contains much volatile matter, burns with flame, and is suitable for gas-making. The dull soft matter often noticeable between harder layers is called *mother-coal.* Coals are named from the mines they are or were originally got from. A well-known mine near the end of the Roman wall on the coast of Northumberland yielded the familiar *Wallsend coal,* but after being worked for upwards of eighty years, was closed in 1855.

Sometimes the hydrocarbon gases (known to the miners as "fire damp") which are imprisoned in the coal escape, and, mixing with the air in the mine, render it explosive, and cause frequent and serious accidents. These explosions are made still more serious because the oxygen of the air is converted, by union with the hydrogen and carbon of the gas, into steam and carbonic acid ("choke damp"), so that those who escape the first danger are suffocated.

From what has been said, there can be no doubt that the beds of coal are really buried forests, and the presence of the underclay with its roots and the occasionally erect trunks proves that the coal-beds were formed on the spot where the forests grew, and not by drifted matter settling down in lakes and estuaries. In the whole thickness of the coal measures there are perhaps a hundred or more beds of coal separated from each other by many yards of shale and sandstone. We must, therefore, imagine somewhat unusual conditions to have prevailed, because in the same locality there must have been a whole series of forest growths one after the other. Each growth was evidently brought to an end by the influx of water, which caused the trees to rot and fall, and finally buried them under a thick layer of mud and sand. At the end of the Millstone Grit period, then, we must suppose the shallow sand-choked sea to have been gradually converted into land high enough to support a dense vegetation somewhat like that of a tropical jungle. Subsidence must then have occurred, and have been continued long enough to allow this vegetation to become buried under sediment which again gradually became land, and gave rise to another forest, which was in its turn submerged and buried. This peculiar oscillating condition must have continued through a very long period, until a sufficient number of these forests were buried to form the beds of coal.

There are other minerals besides coal in the coal measures. Iron pyrites has been mentioned; in the coal it is objectionable, but some of the shales are rich in it, and are largely used in the manufacture of alum. By exposure to the weather the pyrites is converted into ferrous sulphate ($FeSO_4$) and sulphuric anhydride (SO_3). This latter substance acts upon the alumina of the shale, and converts it into aluminium sulphate ($Al_2O_3 + 3SO_3$). To this either potash or ammonia is added to form common alum, which is the double sulphate of aluminium and either potash or ammonium ($Al_2O_3,K_2O + 4SO_3$).

Another more important compound of iron is the carbonate ($FeCO_3$), which, mixed with clayey impurity, forms nodules which are found in layers at various levels between the beds of coal, and are frequently worked in the same pit. These nodules seem to be concretions which have formed round some organic substance, such as a shell or fern-frond. Many fine specimens of the latter are found on breaking them open. The nodules contain about a third of their weight of pure iron, and are very largely worked in Yorkshire.

The underclays, being generally very free from lime, alkalis, and other fusible material, are excellent fireclays, and are used for lining blast furnaces, crucibles, etc., especially the siliceous clays of the lower coal measures, known as *gannister.*

The coal-measure sandstones are often good building-stones; those which are more micaceous or flaggy are suitable, according to their thickness, for paving or roofing. In the Bristol coal-field there is a very thick and valuable sandstone known as the *Pennant rock.*

Since their deposition the carboniferous strata have been bent into folds, and much of the coal measures has been denuded away from the higher portions, so that the existing coal-fields are only fragments of what they were originally. This is notably the case in Ireland, where most of the higher carboniferous strata have been removed, and a great floor of limestone left, with here and there a fragment of the coal measures still lying on the top of it in sheltered hollows. No doubt most of the English coal-fields were once continuous. If so, those of the north must have been elevated higher than the summits of the existing Yorkshire hills, many of which are at present topped with millstone grit, a rock lower in position than the coal measures. A piece of evidence in support of this theory exists in the presence of a small isolated coal-field at the foot of Ingleborough, where it has been brought down from a higher level by the great Pennine fault, and so preserved. In addition to the coal measures which have been lost by denudation, there are others which are lost to us through being too deeply covered with more recent strata. For example the York, Derby, and Nottingham coal measures

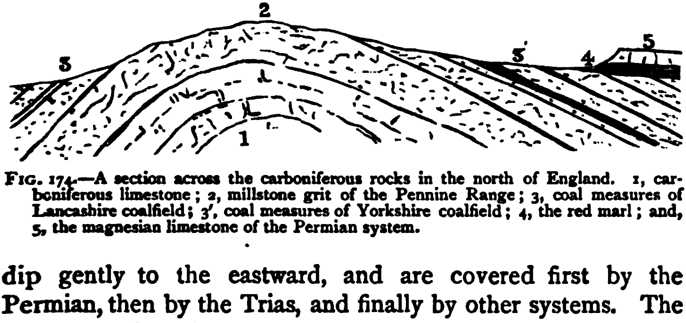


Fig. 174.—A section across the carboniferous rocks in the north of England. 1, carboniferous limestone; 2, millstone grit of the Pennine Range; 3, coal measures of Lancashire coalfield; 3′, coal measures of Yorkshire coalfield; 4, the red marl; and, 5, the magnesian limestone of the Permian system.

dip gently to the eastward, and are covered first by the Permian, then by the Trias, and finally by other systems. The presence of coal measures at Dover has been proved by a boring carried down through the chalk. These are no doubt a continuation underground of the Belgian coal-field, and it is thought quite possible that coal may exist within workable distance of the surface in the neighbourhood of London. As the more easily got-at coals are exhausted, such buried coal-fields will to a certain extent be available, and the demonstration of their presence or absence in certain localities is a very important application of geological knowledge. Our coals are being used at present at the rate of over 120 million tons a year, with a tendency to increase, and the question of the amount still available has been made the subject of inquiry by a royal commission. The commission concluded that by working down to a depth of four thousand feet, which, though not yet done, they considered possible, and by utilizing the coals to that depth which lie under more recent strata, there was enough coal to last at the present rate for over twelve hundred years, but that if the present rate of increase is maintained they will only last three hundred or four hundred years. As a matter of fact they are never likely to be worked out in this manner, as it would become cheaper to import them from America or elsewhere.

The fossils of the carboniferous system are twofold, the marine fossils chiefly found in the limestone, and the plants of the coal measures.

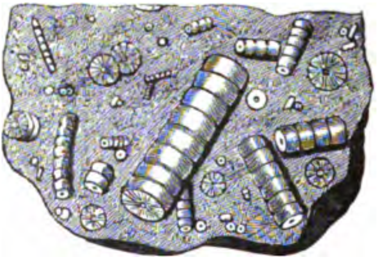


FIG. 175.—Limestone showing stems of Encrinites.

The limestone in some parts seems to be almost entirely composed of corals, in other parts of encrinites, and in others of bivalve and brachiopod shells. On breaking a piece of fossiliferous limestone, it is not always easy to distinguish the fossils, which seem to be completely blended into the stone; but they are really harder than the rocky matrix, and whenever the rock has been exposed to the action of the weather, the fossils stand out beautifully in relief on its surface. In this way many of the finest specimens of encrinites and corals have been obtained.

The most noteworthy corals are, perhaps, *Lithostrotion*, a massive columnar coral, and *Syringopora*, a kind of "organ-pipe" coral. *Favosites* is now extinct. The crinoids are very abundant, especially in some of the Derbyshire limestones, which, when polished, are used for decorative purposes. Broken portions of the stalks of encrinites are much more abundant than the heads, the latter being comparatively scarce (see Fig. 177). Brachiopods are very abundant and distinctive, species of *Productus* (Figs. 180, 181), *Spirifer*, and *Rhynchonella* (Fig. 182) being most common. From this time they gradually decline in numbers and importance.

Lamellibranchiata are very much more abundant than previously, and continue to increase down to the present time. One of the most familiar is a kind of mussel called *Anthracosia*, and an *Aviculopecten* (Figs. 183, 184), both of which are found in the coal measures. Among Gasteropods, *Euomphalus* may be noticed. In Canada specimens of a *Pupa*, a small air-breathing gasteropod, have been collected. Cephalopods are highly developed and numerous, *Orthoceras* and *Goniatites* being common.

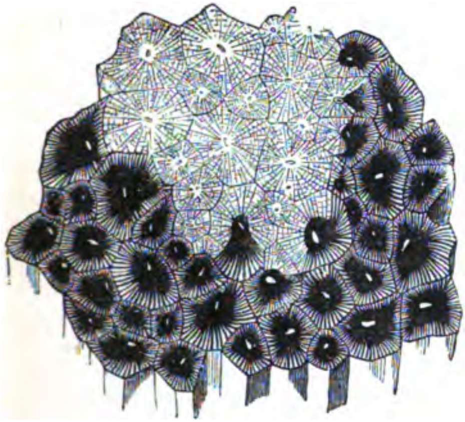


FIG. 176.—*Lithostrotion*.

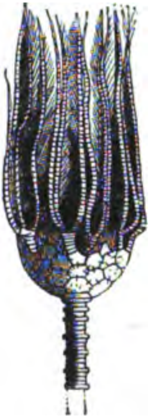


FIG. 177.—*Actinocrinus*, a carboniferous crinoid.

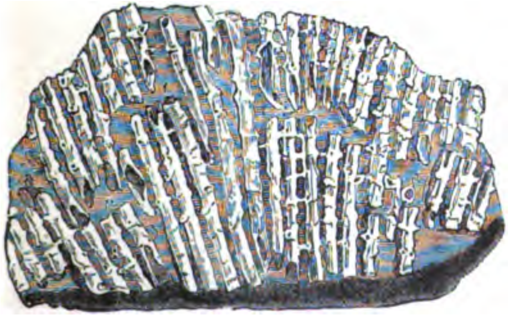


FIG. 178.—*Syringopora*.

There is a large development of small bivalved crustaceans called *Entomostraca*, and representatives of the modern lobster and cray-fish make their appearance; but trilobites are dying out, *Phillipsia* being one of the last to survive, and the *Eurypterida*, which flourished in upper Silurian and Devonian times, now also die out.

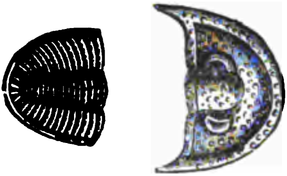


Fig. 179.—Phillipsia, head and tail pieces.

There is abundant evidence of various kinds of fish, many of new types, both in the limestones and in the coal measures. The remains, though numerous, are mostly fragmentary, consisting of palatal teeth and spines in the limestones, and the bony enamelled plates of ganoids in the coal measures.

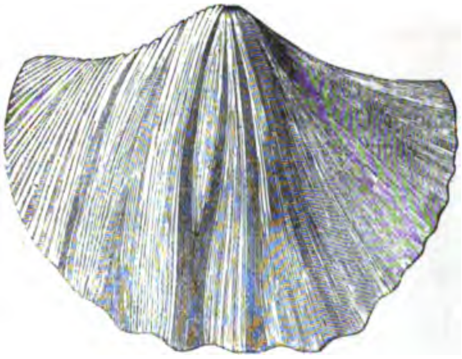


Fig. 180.—*Productus giganteus*.

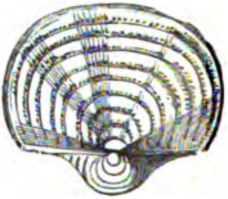


Fig. 181.—*Productus punctatus*.

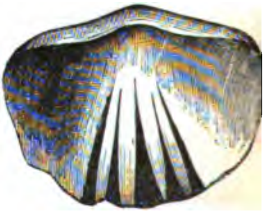


Fig. 182.—*Rhynchonella pugnus*.

Some Carboniferous Brachiopods.

The next class of vertebrates, the Amphibia, now appears for the first time. All the species belong to an order, the *Labyrinthodonts*, now extinct. They were lizard-shaped animals, and received their name from the labyrinthine pattern exhibited by the enamel in a section of their teeth. Small amphibians have also been found in fossil tree-trunks in Nova Scotia.

The coal measures have yielded the remains of over three hundred species of plants, a great advance on anything which has preceded. They are for the most part very fragmentary, and, as has been explained, are chiefly found in the shales which lie on the top of the beds of coal. They belong to the *cryptogamous*, or non-flowering, division of the vegetable kingdom, and are remarkable for their gigantic size as compared with their modern representatives. For example, the Equisetaceæ are now represented by the familiar "horsetails," which grow in waste swampy places, and attain a height of only one

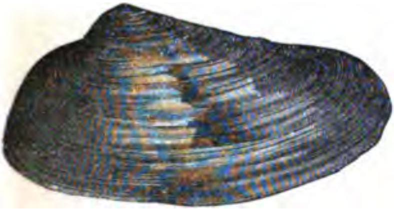


FIG. 183.—*Anthracosia.*

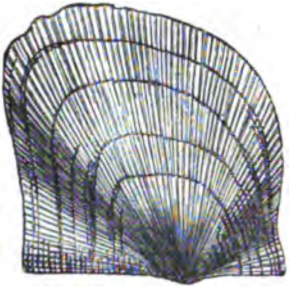


FIG. 184.—*Aviculopecten.*

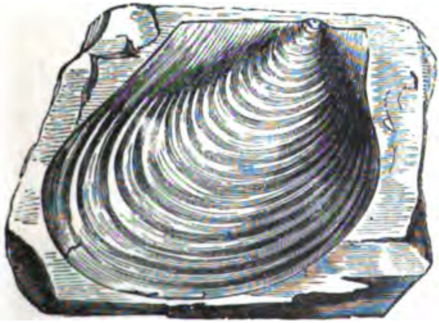


FIG. 185.—*Posidonia.*

SOME CARBONIFEROUS BIVALVES.

or two feet. In the coal measures they are represented by the *Calamites*, which reach the height of thirty feet, and are not uncommonly found erect. The stems are fluted and jointed at intervals, and are often six inches in diameter. The great tree-trunks which are found in the coal measures are really only casts, formed probably in the following manner. The tree was killed by the inundation of water, and the mud and sand which accompanied it, and the central portion rotted away while the bark remained. The hollow trunk was then gradually filled with the fine muddy sand in which it was buried, and, in process of time, the bark rotted away and was removed, or, perhaps, remained in its original position and was carbonized or converted into coal. It is the internal sandstone cast which now constitutes the fossil, and the

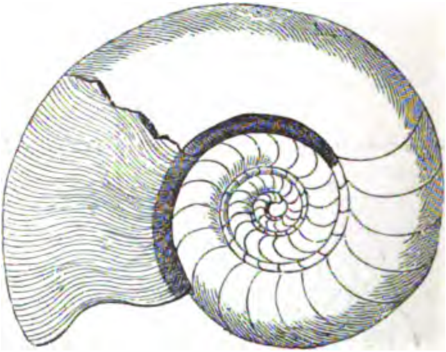


FIG. 186.—*Nautilus* (a cephalopod).

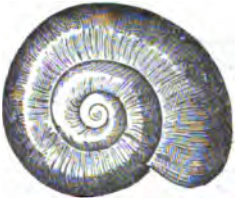


FIG. 187.—*Euomphalus* (a gasteropod).

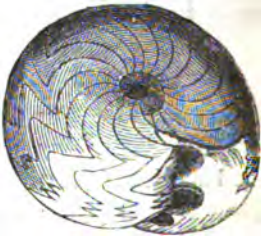


FIG. 188.—*Goniatite* (a cephalopod).

flutings and marks on its exterior are really a cast of the interior surface of the bark.

Another notable coal fossil is the *Lepidodendron*. This is a gigantic representative of the modern club moss, a small creeping plant which is found growing among the heather on our northern hills. The Lepidodendron, however, was often fifty feet high, and its remains are readily recognized by the diagonal pattern produced by the scars of its fallen leaves. Its fruit, something like a small fir-cone, is called *lepidostrobus*.

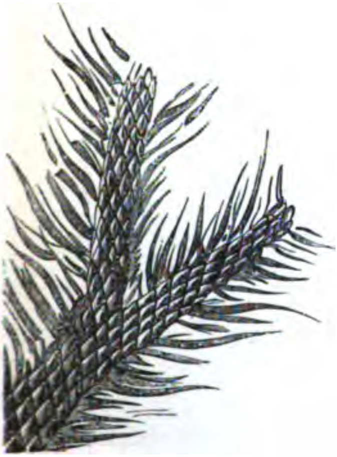


FIG. 189.—Branch of *Lepidodendron*.

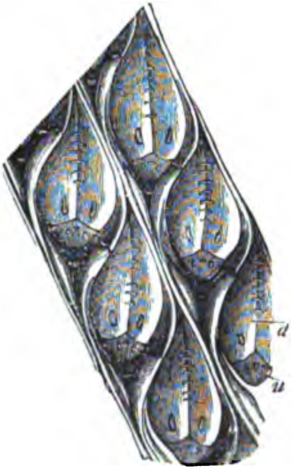


FIG. 190.—Portion of *Lepidodendron* enlarged, showing the leaf-scars.

Another tree is the *Sigillaria* (Fig. 191), so called from the seal-like impressions which form vertical lines on its fluted trunk. The root of this plant is called *stigmaria*, and is one of the commonest fossils in the underclays, though its real character was for a long time unknown. In addition to these, huge trunks of fir-like trees, perhaps allied to the yews, have been found lying prostrate in the rocks, some reaching a length of sixty or seventy feet.

There was an enormous variety of ferns, many of them tree-ferns of huge dimensions. Of ordinary ferns the chief genera were *Neuropteris*, *Pecopteris*, and *Sphenopteris* (Figs. 192, 193); of tree ferns, *Palæopteris* (Fig. 194).

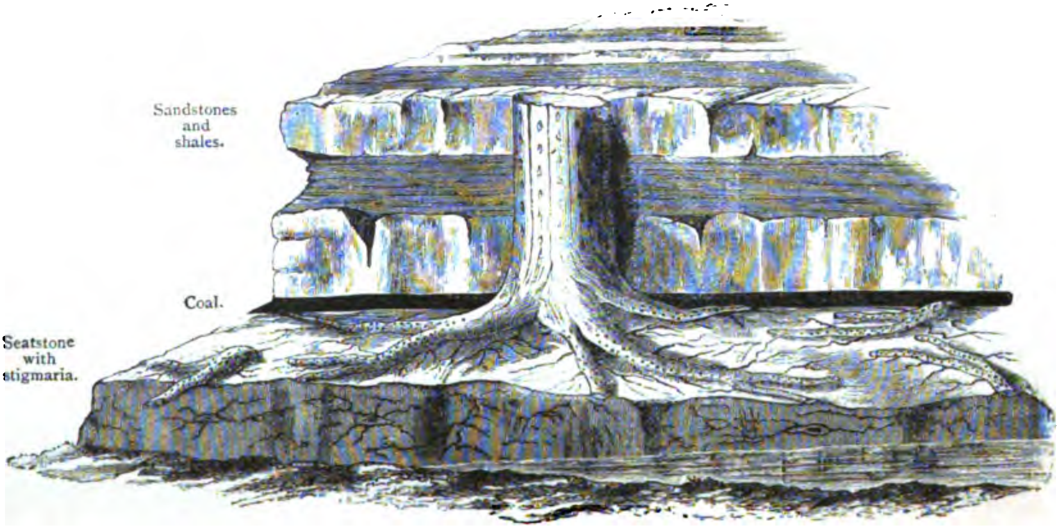

Sandstones and shales.
Coal.
Seatstone with stigmaria.

FIG. 191.—Erect *Sigillaria* rooted in a seatstone full of *stigmaria*.

Among all this mass of vegetation there are no traces of any flowering plants; but we must remember that it only represents the growth of the low swampy grounds. On the higher land there may have been forests of more highly organized plants.

From the general character of the Carboniferous vegetation, combined with its remarkable similarity in distant regions and its extension into the Arctic circle, we are probably right in inferring that the climate of the Carboniferous times was warmer, moister, and more equable than it is at present. It is very difficult to understand the occurrence of reef-building corals, ferns, and tropical-looking plants in the Arctic regions, and in addition to favourable astronomical conditions it may be that some amount of heat was, in these ancient epochs, derived from the heated interior of the earth itself. Possibly, also, the air was richer in carbonic acid than it is now, and this encouraged the profuse and vigorous growth of the vegetation.

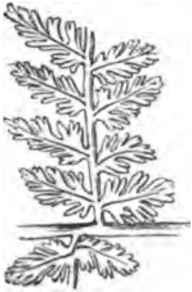


FIG. 192.—*Sphenopteris.*

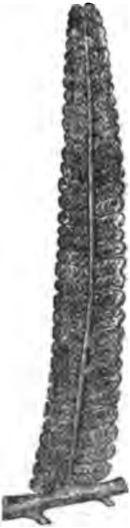


FIG. 193.—*Pecopteris.*

The Carboniferous system as displayed in various continental localities differs in several respects from that of England. In North-east France and Belgium there are important coal-fields; the measures are very much contorted, fractured, and disturbed, and are underlaid by thick carboniferous limestone. In West Prussia and the Rhine Province there is an important coal-field of enormous thickness, but the carboniferous limestone is represented by schists, grauwacké, and sandstones. In Russia there is a large extent of carboniferous limestone, but, as in Ireland, the coal measures are practically absent. The Silesian coal-field is noted for containing a seam of coal fifty feet thick, the thickest known. The southern European peninsulas contain no coals except a small field in the north of Spain, which has been very little worked.

The Indian coals are not of Carboniferous age. There are coal-fields in Japan, Borneo, China, the Cape; and also in Australia, where, in New South Wales, there is a field of carboniferous age, and others in Queensland more recent.

There are large supplies of coal in the United States and Canada, where the carboniferous system has the same general order of succession as in England, *i.e.* limestone below, sandstone in the middle, and coal measures on the top. The fossils also are remarkably similar, even to the species. The limestone contains crinoids, corals, spirifers, productus, etc. There are ganoid fishes in the coal measures, and, as in Europe, amphibia make their first appearance. Calamites, lycopods, sigillaria, and ferns abound, and there are underclays with stigmaria and other fossils. The coal-fields of the United States are estimated to cover an area as large as France, those of Canada an area larger than Wales. In the Nova Scotia coal-field the beds are very thick, one of them attaining the thickness of thirty-eight feet.

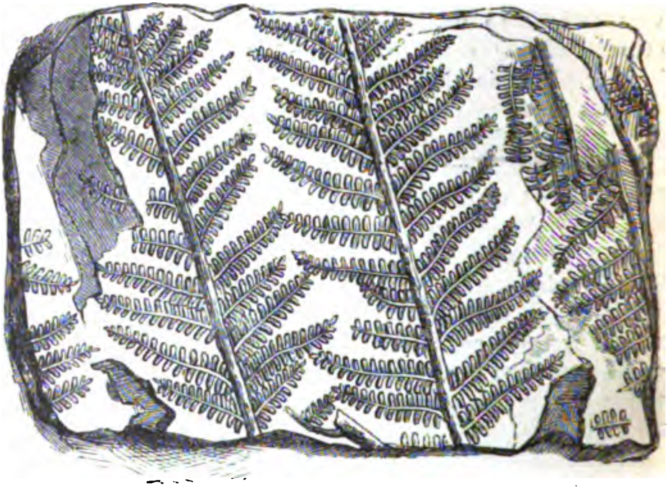


FIG. 194.—Fronds of a tree fern.

The industrial products of the system have been fully dwelt on. They comprise coal, iron, lead, zinc, fire-clay, alum shales; millstone grit and sandstone for building; limestone for road-mending, lime, and decorative work; and many minor products, such as fluor spar, heavy spar, etc.

The soil of the Carboniferous districts is not on the whole very fertile, though there are exceptions. The limestone is covered with thin soil, and supports a scanty but sweet pasturage; the millstone-grit areas are generally high and barren; and the coal-fields, though in parts fertile, are for the most part enveloped under a dense pall of smoke, and buried under the refuse of the mines and iron works.

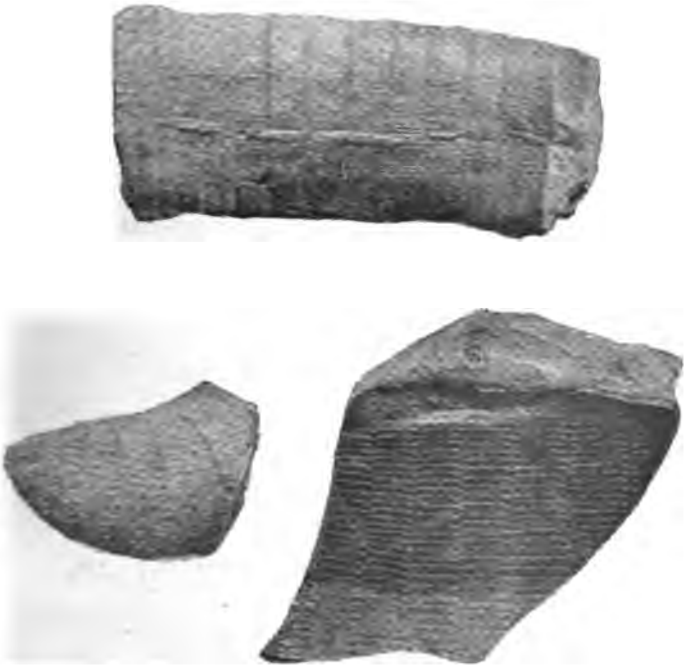


FIG. 195.—Calamites from the coal measures. (Jermyn Street Museum.)

SUMMARY.—The lower part of the carboniferous system in England consists of massive limestone with shales, and thin

THE CARBONIFEROUS SYSTEM.

Scale:—1 inch = 2,000 feet; about 10,000 feet

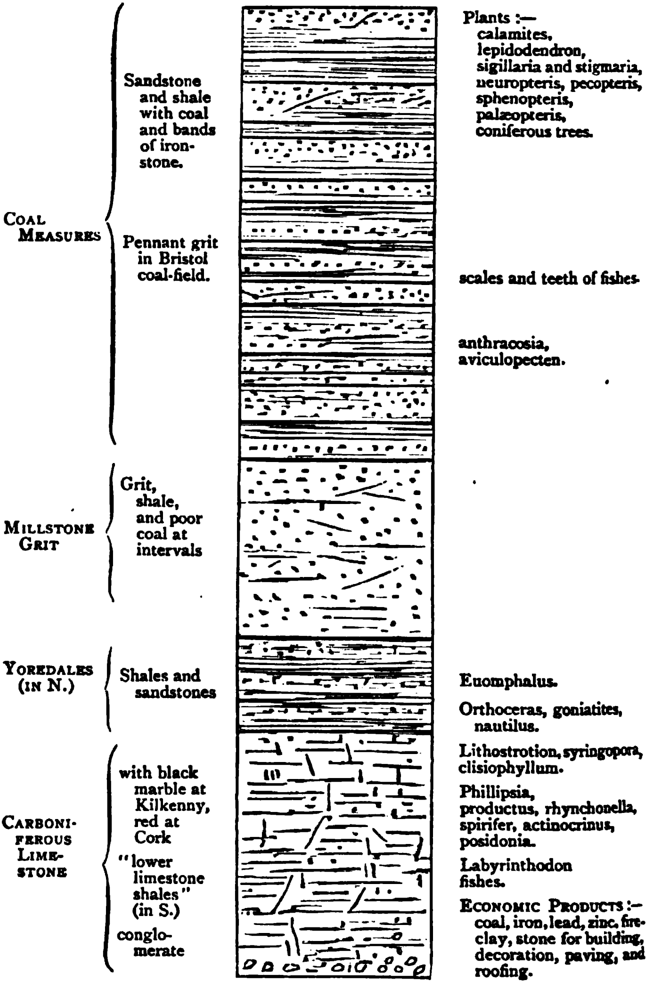

Coal Measures
Sandstone and shale with coal and bands of iron-stone.
Pennant grit in Bristol coal-field.
Millstone Grit
Grit, shale, and poor coal at intervals
Yoredales (in N.)
Shales and sandstones
Carboniferous Limestone
with black marble at Kilkenny, red at Cork
"lower limestone shales" (in S.)
conglomerate
Plants :—
calamites,
lepidodendron,
sigillaria and stigmaria,
neuropteris, pecopteris,
sphenopteris,
palæopteris,
coniferous trees.
scales and teeth of fishes.
anthracosia,
aviculopecten.
Euomphalus.
Orthoceras, goniatites, nautilus.
Lithostrotion, syringopora, clisiophyllum.
Phillipsia,
productus, rhynchonella, spirifer, actinocrinus, posidonia.
Labyrinthodon fishes.
Economic Products :—
coal, iron, lead, zinc, fire-clay, stone for building, decoration, paving, and roofing.

Fig. 196.

limestones and sandstones above and below, the whole mass being represented in Scotland by a series of shales and sandstones with coals and iron ore. The limestone is succeeded by the millstone grit, which is well developed in Derbyshire and Yorkshire, and the grit by a thick series of shales and sandstones with the numerous beds of coal which form the special character of the system. The Carboniferous system, like all the rest, indeed, varies much in different parts of the world. In France, Belgium, and the United States, coal measures are present, but in India coal is entirely absent from the system.

QUESTIONS.

1. What are the special features of the Carboniferous system? To what extent is the name a suitable one?
2. Describe the Mountain Limestone; its character, composition, and the changes it undergoes in various localities. By what beds is it represented in Scotland?
3. What geographical changes led to the deposition of the Millstone Grit upon the limestone? Describe the grit and discuss its origin.
4. Describe the physical changes which led to the deposition of the coal-beds. Give the reasons for thinking that coal is formed from vegetation, and describe the chemical changes by which the coal was formed.
5. What reasons are there for thinking that the coal-beds were formed *in situ*, and are not accumulations of drifted matter?
6. What other commercial products do the coal measures yield?
7. Discuss the question of the British coal-supply of the future.
8. Classify zoologically, and give the formation in which the following fossils are found:—*Lithostrotion*, *anthracosia*, *spirifer*, *phillipsia*, *calamites*, *euomphalus*, *pecopteris*.
9. Mention any noteworthy facts about the Carboniferous strata of the United States, India, Silesia, Belgium, Nova Scotia.
10. What are the agricultural capabilities of the British Carboniferous districts?

CHAPTER XXIII.

THE PERMIAN SYSTEM.

THE Carboniferous system is succeeded by a series of rocks to which the name of **New Red Sandstone** has been given. The name is generally descriptive, though they are not all *sandstones* or all *red*, and the prefix *new* was added to distinguish them from the other red series, which lies below the Carboniferous. So far as the physical character of the rocks is concerned, the series is very much alike throughout, and was evidently deposited under somewhat similar geographical conditions. It consists of coarse breccias and conglomerates, red sandstones and marls, thin and thick limestones, and deposits of salt and other matters, evidently derived from the evaporation of sea-water. In some localities some deposits prevail while others are attenuated or altogether absent, and it is not always easy or even possible to exactly correlate them as regards their exact period of deposition; but this is the case more or less with all geological systems, especially in widely separated localities. Looking merely at the rocks themselves no one would think of separating them into two distinct systems, but when the fossils of the various strata are examined it is found that while those of the lower half of the series have a strong general resemblance to those of the Carboniferous system, and in some cases are identical, those of the upper half are entirely different, and have affinities with the fossils of the systems which follow, rather than with those which precede. The systems which precede belong to the Palæozoic group, those which follow to the Mesozoic, consequently the lower section of the New Red Sandstone, called the **Permian**, is placed in the former group, and the upper, called the **Trias**, in the latter.

The Permian system derives its name from the province of Perm in the east of Russia, where it was studied and named by Sir R. Murchison. It is well displayed in England and Scotland, but rather poorly in Ireland. In England it lies in two lines along the east and west slopes of the Pennine anticlinal, and extends in a gradually narrowing strip down into Devonshire. A considerable rise and disturbance of the land seems to have brought the Carboniferous period to a close, the low flat swamps in which the coal vegetation flourished being elevated so as to form a ridge running north and south with a lake on each side. After considerable denudation had taken place, these lakes became the receptacles of the Permian strata, which were laid down unconformably on the coal measures, and in some places overlapped them. The same unconformity between Carboniferous and Permian exists also in Germany; but in France there is no apparent break, even the coal-seams and Carboniferous flora are continued upwards into what are generally recognized as Permian strata. These French strata were no doubt laid down while upheaval and denudation were taking place in other localities.

The Permian system is generally divided into upper and lower divisions. The lower, to which the German term *Rothliegende* ("red-layers") has been applied, consists of thick, coarse conglomerates and breccias, with red marls and sandstones. In England the breccia varies in thickness, from a hundred to four hundred feet, and both here and elsewhere is interesting in many ways. The stones of which it is composed are very large, sometimes three or four feet long, and they represent an almost complete series of the older rocks, including granite, gneiss, and schist, with various rocks of the Cambrian and Silurian systems, and are embedded in a fine red-coloured clayey or sandy matrix. Some of these stones have smooth flat sides, and are sometimes smoothed and scratched, and on the whole bear considerable resemblance to modern moraine matter. It has been pointed out that they are not known, in any European locality, to rest on a glaciated rock surface, as do many modern glacial deposits, as well as those of the so-called "glacial epoch," and also that the occasional smoothed and scratched stones may be "slickensided" fragments, detached from the surface of a fault, or may have been scratched in other ways. The evidence of fossils has also been appealed to. The deposits of the more recent and undoubted glacial epoch are accompanied by the fossils of creatures whose representatives now inhabit Arctic waters, while these lower Permian strata contain fossils like those of the coal period which was the reverse of glacial. On the other hand, some of the fossils attributed to Permian times have been proved to be in strata which are stained red, and look like, and were mistaken for, Permian, but

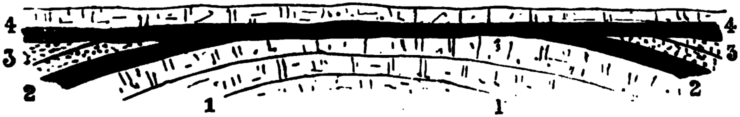


FIG. 197.—Section from Durham to South Yorkshire. The Permian (4) resting unconformably upon the mountain limestone (1), the Yoredales and Millstone grit (2), and the coal measures (3).

which are really coal measures; and it should also be noted that enormous numbers of coal-measure fossils do not occur, and that, of the few which do, many have a dwarfed and stunted appearance, as if the conditions in which they lived did not altogether suit them.

But another striking fact is, that in India, the Cape, and in Australia very similar breccias of large extent are described by competent observers which present exactly the same appearance, and belong apparently to the same epoch, and which are seen in places to repose on glaciated surfaces *in situ*. The astronomical explanation of the glacial epoch will not allow of glaciation in countries on opposite sides of the equator at the same time, but the difference of time would not be long as compared with a geological period. The high mountains which in these latitudes would be required to augment the effect of the astronomical causes in order to produce such extensive glaciation do not exist at present, but there are everywhere on the earth's crust such proofs of extensive denudation and change of level that they may have once existed, and have been long since removed.

The balance of evidence on the whole seems favourable to the idea that in these early Permian times there occurred either one or a series of glacial epochs, and that these breccias are portions of the old moraines which have escaped destruction. The Rothliegende attains an enormous thickness in Bavaria, with a remarkable development of coarse conglomerate, containing huge masses of igneous and metamorphic rocks.

The upper Permian, called by the Germans *Zechstein* ("minestone," from the copper associated with it), consists in England of a yellow limestone, composed of a mixture of the carbonates of lime and magnesia, called the **Magnesian Limestone**, with "marl slate" below, and red marls and sandstones above. The escarpment of the magnesian limestone runs northward from Nottingham across Yorkshire to Durham, overlapping some of the lower Permian beds, and resting unconformably upon the various members of the Carboniferous system. In thickness it ranges from two hundred feet in Nottinghamshire to six hundred in Durham, and it is often divided by a central layer of marl. It varies much in character, being at one place soft and crumbling, and at another hard and crystalline. On the coast of Durham, near Tynemouth, it puts on a very peculiar appearance, being very nodular and concretionary, and, where weathered in the cliff, presenting the appearance of a mass of cannon-balls. In some places in Yorkshire a chemical change has taken place, resulting in the separation of the carbonate of lime, and the leaving behind of a loose mass of magnesian sand and marl. Its southern portion is largely used as a building-stone, but its qualities under this head have been described in a previous chapter.

The **Marl slate** is a laminated shaley limestone, and is noted for its fish remains both in England and Germany. In the latter country it goes under the name of *Kupfer-scheifer* (" copper-slate "), on account of the copper ores which it yields.

As with all red-coloured strata, fossils, except in special layers, are rare. No doubt this is mainly due, as in the case of the Old Red, to the presence of iron salts in the waters. The vegetation seems to have borne a general resemblance to that of the preceding period, old species of *Calamites*, *Lepidodendron*, and several coal-measure ferns, such as *Sphenopteris* and *Neuropteris*, being found, but important additions are made to the Conifers by the new forms of *Walchia* and *Ullmania*, which are very characteristic of the Permian. Cycads, such as *Noeggerathia*, also occur. Sigillaria and Stigmaria have disappeared.

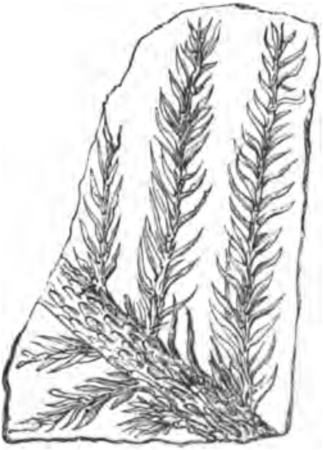


FIG. 198.—*Walchia.*

The fauna is also comparatively scanty, and is for the most part confined to the marl slates and the magnesian limestone. There again we find new species of Carboniferous genera, such as a spiny productus, *P. horridus*, *Spirifer alata*, and several new Lamellibranchs of the genera

Gervillia, *Avicula*, and *Pecten*. As might be expected, such denizens of the open sea as corals and cephalopods are rare, the latter being represented only by a species of Nautilus, whereas, in the Carboniferous system, 175 species have been found. Trilobites also have quite disappeared, though other forms of crustaceans are found.

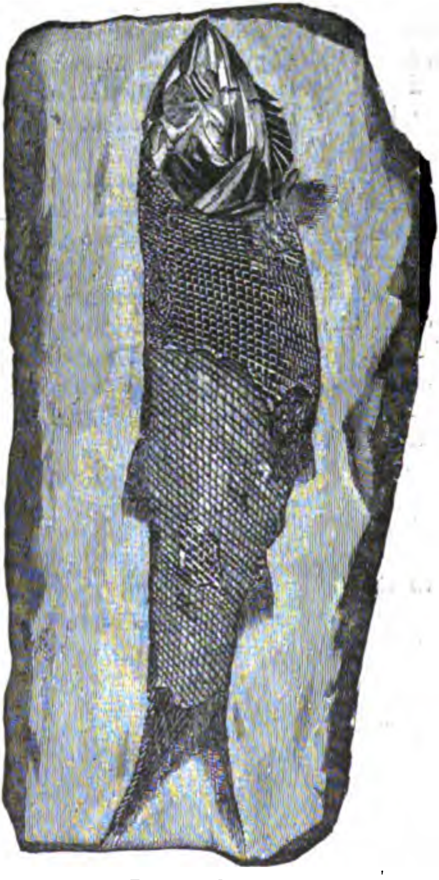


Fig. 199.—*Palæoniscus.*

The Permian fishes are important and characteristic; they are all "heterocercal," after the Palæozoic type, but consist of new species. They are mostly found in the marl slate, both in England and in Germany, the most noteworthy being *Palæoniscus* and *Platysomus.* In Germany, also, the marl slate, or *kupferscheifer*, has yielded a remarkable series of very perfect amphibian fossils of more than fifty different species. They are mostly small, but in other respects they vary very much. Amphibia are also found in England, together with true reptilian remains. *Protosaurus*, a kind of lizard, is the first representative of the latter class. Footprints in the sandstones of Dumfries have been referred to reptiles, though they may be those of labyrinthodonts.

The Zechstein of Saxony is celebrated for its very remarkable series of beds of common salt, and chlorides and sulphates of the alkalis and alkaline earths, apparently derived from the total evaporation of sea-water. Some of these deposits are some hundreds of feet thick; and near Berlin a bed of rock salt, 3,800 feet thick, probably belonging to the same period, has been lately penetrated by an artesian boring.

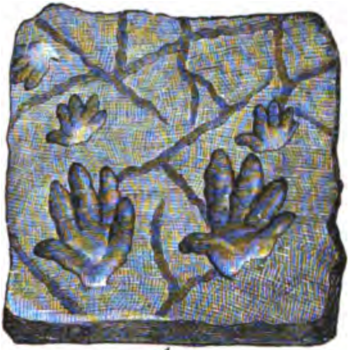


FIG. 200.—Footprints of *Labyrinthodon*, an amphibian.

The Permian beds of Russia cover a large area, and are somewhat similar in character and in fossils to those of Germany and England. The upper division contains deposits of malachite and other copper-bearing minerals.

In America there is no break between the Carboniferous and Permian strata; and the flora and fauna, though scanty, are, for the most part, coincident with those of the beds below. A considerable number of true reptilian species have, however, been found.

The industrial products of the system are magnesian limestone and red sandstone for building, clays and marls for brickmaking. In Germany, salt and other chemical products are obtained; but these in England are found in the succeeding system.

The Permian region, like that of the next system, is characterized by the rich red colour of its cliffs and soil. The marly soil is damp and heavy; that on the limestone dry and light.

SUMMARY.—1. The New Red Sandstone is divided into a lower Palæozoic portion, the *Permian*, and an upper Mesozoic portion, the *Trias.* These portions are similar in mineral character, but differ in their fossils. The English Permian strata are mostly lacustrine, and the lower beds possibly glacial. They are impregnated with iron, and generally unfossiliferous.

THE PERMIAN SYSTEM.

Scale: 1 inch = 500 feet; about 2,000 feet.

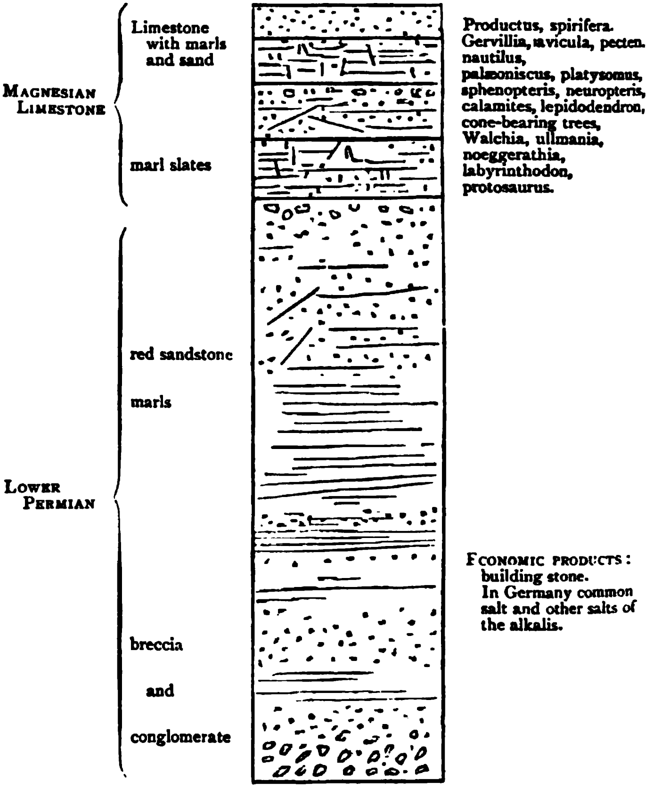


Fig. 201.

QUESTIONS.

1. On what principle has the New Red Sandstone Series been cut into two portions? In what respects do these divisions differ from and resemble each other?
2. What changes occurred at the end of the Carboniferous period, and under what conditions were the Permian strata probably deposited?
3. Describe the Permian breccia, and discuss its origin.
4. Describe the geological position, chemical character, and possible origin of the Magnesian Limestone.
5. Explain the terms *rothliegende*, *zechstein*, *kupfer-scheifer*.
6. What old and what new vegetable fossils are found in Permian strata. Describe their characters.
7. Compare the Permian with the Carboniferous fauna.
8. For what are the *kupfer-scheifer* and *zechstein* of Germany respectively noted.
9. Give details respecting the Permian system as developed in (*a*) Russia, (*b*) North America.
10. Describe the industrial products and agricultural character of the Permian strata.

CHAPTER XXIV.

THE TRIASSIC SYSTEM.

It has already been explained that the difference between the Permian and Triassic systems is palæontological rather than physical, and that where fossil evidence is absent, as is frequently the case, it is very difficult, and sometimes, indeed, impossible, to decide to which of the two systems a stratum belongs. The fossils, however, though scanty, except in certain beds, are quite abundant enough to mark the great change which has gradually taken place. The great disturbance which, at the end of the Carboniferous period, resulted in the elevation of the Pennine ridge, and the formation of more or less land-locked areas on each side of it, seems to have been

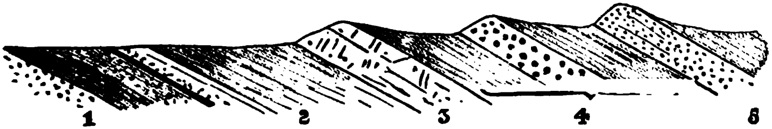


Fig. 202.—Succession of strata from Carboniferous to Trias. 1, Coal measures; 2, Permian marls; 3, Magnesian limestone; 4, Bunter; 5, Keuper.

followed by many minor movements during Triassic times, which culminated in the elevation of an intermittent line of contorted and fractured rocks, extending from the Rhine through the Ardennes, the Mendips, and South Wales, to Ireland. This movement brought about great changes, both in the height of previously existing land and in the depth of the neighbouring sea, and caused such great geographical changes that the affected area, especially the sea, became unfit to support the plant and animal life which had previously flourished. As a consequence, according to their powers of locomotion, they either retreated, died off, or, if sufficiently hardy and adaptable, maintained their ground. In the latter case, by the working of natural selection, their gradual adjustments to the altered circumstances of climate, depth of water, and food-supply, caused those changes which resulted in the evolution of new species and genera better adapted to the new life than their palæozoic ancestors. In this way, aided by the incoming of new species from other parts, we may account for the change in the organic world which meets us in the Triassic system, and which developed into the abundant and varied life of the Mesozoic systems. It must not be supposed that these geographical changes were sudden. No doubt, in very early geological times, when the earth's crust was thin, it was subject to much more violent, sudden, and frequent disturbances than it is at present; but there is not much evidence that this was the case in the times now under consideration. The successive upheaval of the great anticlinals; the submergence of large areas, firstly of the coal measures, and then of the Permian strata; the deepening of the ocean in one place, and its shallowing in another,—all, no doubt, took place slowly and imperceptibly as the result of movements of the earth's crust continued through long ages, and the organic changes brought about by migration, extinction, and adaptation, proceeded *pari passu* with the changes in the inorganic world.

We see in the Triassic system the evidence of those changes; firstly, in the great masses of breccia and conglomerate, which are abundant in its lower division; secondly, in the frequent false bedding, local unconformity, and overlapping of the strata; and, thirdly, in the appearance of new types of life, all the Palæozoic species and many of the genera being replaced by new ones. The latter change is, no doubt, rendered more marked by the fact that most of the Triassic rocks are practically unfossiliferous, and that the greater number of fossils have been collected from the Rhætic beds which lie at the very top, and which were therefore deposited at a time considerably removed from the Permian period. In the Tyrol, however, there are limestones known as the St. Cassian and Halstatt beds, which contain genera of Palæozoic fossils, such as *Orthoceras*, *Bellerophon*, and *Euomphalus*, modified, however, into new species, associated with the purely Mesozoic forms of *Ceratites*, *Ammonites*, *Gervillia*, and others. Whatever may be the explanation of this admixture, whether the Palæozoic forms had maintained their position, or had returned after migration and mingled with the new forms which they found in possession, it shows that, as in all other cases, the organic changes proceeded slowly, that there was nothing like a sudden blotting out and extinction of the old forms of life.

The new conditions seem to have been much less favourable to Brachiopoda, and more favourable to Lamellibranchiata, the relative numbers of the members of these classes having altered considerably. Changes such as this, and the permanence through the Mesozoic era of the new types now introduced, bear witness to the extensive nature of the unconformity between the Permian and Trias.

The Triassic system received its name in Germany, from the fact that in that country it is very readily divisible into three parts, but the name is not so applicable to the system in England, as the middle German division is missing, or, at any rate, is represented by beds which cannot be distinguished from the rest.

The system may be generally described as a series of coloured sandstones and marls, mainly red, conglomerate in parts, thin limestones, and beds of salt and gypsum. The total thickness in England varies from about a thousand feet in the centre of England to five thousand in Cheshire and Lancashire. It occupies, in an irregular fashion, a narrow tract of country from the mouth of the Tees to Devonshire, spreading out considerably in the midlands, and stretching far and wide through Staffordshire into Cheshire and South and East Lancashire. Small areas also exist in the county of Elgin in Scotland, and in the north of Ireland.

The lower division is called the **Bunter** (German = "many coloured"). It is composed of soft, and variegated, and often false-bedded sandstones at the top and bottom, with generally a bed of conglomerate or breccia in the middle, varying in thickness up to a thousand feet. The total thickness of the division varies from one thousand to two thousand feet. It is entirely destitute of fossils, except a few footprints and plant impressions. The conglomerate is somewhat remarkable. It is found, not only near the base of the Bunter beds, but at the base of any other Triassic strata which rest directly on the older rocks. A glacial origin has been claimed for it, but the evidence is not very strong. Its contents are more local than those in the Permian breccia, consisting in the midlands of Palæozoic grits and slates, some containing fossils, and evidently derived from the ancient land of which Charnwood is the surviving relic. In Devonshire it contains pebbles of Dartmoor granite, Cornish slate, and Carboniferous grit, embedded in a dolomitic cement. In Staffordshire and elsewhere the pebbles consist largely of quartzite, derived from Silurian strata. In all cases these conglomerates are evidently shore-deposits derived from the cliffs and high ground of the period, and it is quite possible that these ancient mountains were high enough to have given rise to glaciers here and there, which brought down their moraines to mingle with the shingle of the sea-beach. The conglomerate varies considerably as regards texture, and is in some cases represented by sandstone, as, for instance, at Chester, where the cathedral is built of it, and at Nottingham, where it is perforated by the well-known caves. The breccias and sandstones are often irregularly impregnated with iron-oxide, and weather into fantastic shapes in the cliffs.

The Triassic beds, owing to the changes of level which have been described, do not rest conformably upon the Permian in many localities. In Derbyshire they lie on the Carboniferous rocks, and in Leicestershire on the Pre-Cambrian rocks of Charnwood, where the Keuper marls often contain fragments of Charnwood rock.

The **Muschelkalk** ("mussel-chalk," *i.e.* "shell-limestone") is a series of light-coloured compact fossiliferous limestones and marls, attaining, in the neighbourhood of the Vosges, a thickness of several hundred feet. It contains several species of *Ceratites* (a kind of Ammonite) and of encrinites, mostly, as usual, in fragments, notably *Encrinus liliiformis.* Of bivalves *Gervillia* and species of *Trigonia* are characteristic, and there are also present remains of amphibians, reptiles, and fishes.

The upper division of the Trias is called the **Keuper**, a name of doubtful meaning (*kupfer*, copper?) applied to it by German miners. In England it consists at the bottom of a coarse and variable breccia or conglomerate already described, with sandstones and occasionally marls. These are followed by thinly laminated micaceous sandstones, known as the "waterstones," which supply a good building-material, and have been used in the construction of Warwick Castle, and also

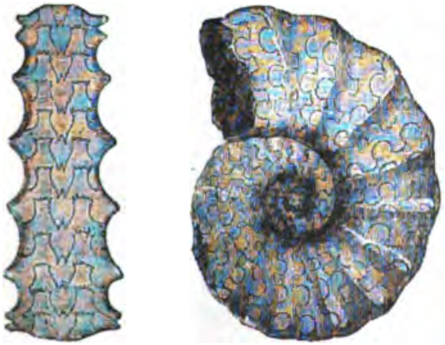


FIG. 203.—*Ceratites nodosus.*

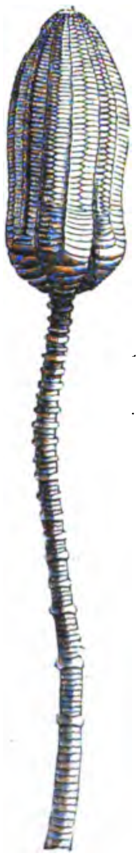


FIG. 204.—*Encrinus liliiformis* (Muschelkalk, Germany.)

give a good supply of water. Over these sandstones come a large series of red and variegated marls, mottled and streaked with lighter colours, with a few sandstones and occasional thin, hard, clayey limestones. This latter series attains in Cheshire a thickness of about three thousand feet, and is of great commercial importance from the beds of salt and gypsum which it contains. The salt-beds are often one or two hundred feet thick; but they are very inconstant, thinning out to nothing in all directions from their thickest parts, so as to form lenticular or lens-shaped masses. This is just the shape a deposit of salt would form if derived from the gradual evaporation of a salt lake or lagoon. Very little salt would be formed at the edges, and deposition would be continued longest in the deepest part, where the last vestiges of the water would linger. When we compare the composition of the dissolved matter in the sea-water, however, with the composition of the Cheshire salt, it becomes evident, either that the sea-water was not completely evaporated in these Triassic lagoons, or that its composition then was different to what it is at present. For example, of the residue obtained by evaporation of sea-water, about 78 per cent. is sodium chloride, or "salt," 8 per cent. is magnesium chloride, 7 per cent. magnesium sulphate, 3½ per cent. calcium sulphate, with smaller quantities of potassium and calcium chlorides, magnesium bromide, calcium carbonate, and other matters. But the Cheshire salt-beds average about 98 per cent. of salt, while several of the above are entirely absent. It must be noted, however, that although there is very little calcium sulphate mixed with the salt, yet it has formed deposits on its own account, it being always the case that beds of salt are associated with beds of gypsum. Both gypsum and salt also frequently impregnate the marls themselves. When a solution of a number of chemical compounds is evaporated, the order in which they will be deposited depends upon the quantity of each compound and on its solubility. In the case of sea-water the calcium sulphate is deposited first, and then the salt, afterwards the other salts in order. It seems, therefore, as if, in some cases, the concentration by evaporation only proceeded far enough to throw down the calcium sulphate and form the beds of gypsum, in others the salt was deposited with a small quantity of the rarer substances; but it was not often that the process was complete and everything deposited. Most probably this consummation was prevented by the rain, as a relatively small quantity of water would be sufficient to keep the minor ingredients in solution. A case has, however, been alluded to, in the preceding chapter, where very nearly all the sea-salts have been thrown down in large beds one over the other.

To produce a vertical series of beds of salt, such as we find in Cheshire and other localities, requires a condition of things something like that which must have prevailed during the formation of the coal measures. Lagoons and salt lakes must be imagined to have undergone prolonged evaporation, then to have gradually subsided sufficiently to be buried under a great thickness of calcareous mud, and this process to have been repeated many times, until the bed of the first lagoon was buried under many hundred feet of strata. The Keuper marls of Cheshire, more than half a mile in thickness, give some idea of the enormous time during which this state of things existed.

The salt is obtained from these underground deposits in two ways, by mining in the usual manner, or by pumping up water which has either naturally or artificially obtained admission to the salt. This latter process causes the formation of unsupported cavities in the marl, which lead to sinkings of the ground, and often to destruction of property. Many of these depressions are now filled with water.

In seeking for an existing case at all similar to that described, we are at once struck with the Caspian Sea. This is an enormous salt-water lake, and has at one time been larger, and has in its retreat impregnated all the country around with its salt. We can imagine what a large mass would be formed if it were to be entirely evaporated. But it is difficult to see how, in the case of an inland sea, the process could be repeated over and over again, while with lagoons fringing the sea it is much easier. Rain-pittings, ripple-marks, sun-cracks, and footprints are very common in the Keuper marls, and it is not easy to see how these could be preserved to the extent they appear to have been, if they were made on the shores of a lake which was drying up. This evidence, therefore, also seems to point to the lagoon theory, or at least to salt-water lakes which were frequently in communication with the ocean. The red colour is due to iron oxides, and is more commonly met with in lacustrine than in marine deposits; but Professor Prestwich attributes it to ferruginous clays derived from the decay of the igneous rocks which were poured out abundantly in the periods immediately preceding, and he thinks that the presence of these clays would in very many ways be inimical to life, and account for the paucity of fossils in these red marls.

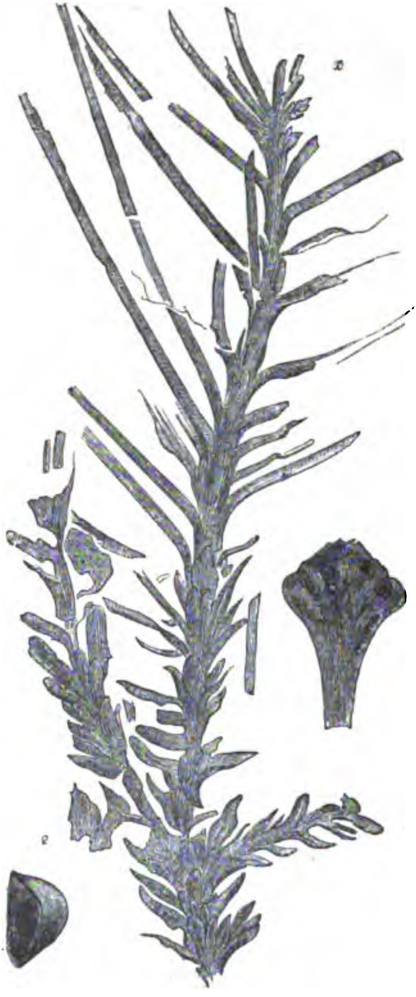


FIG. 205.—Fragment of *Voltzia*.

There is a remarkable absence of shells and marine organisms generally, except a small bivalved crustacean, *Estheria minuta*. Numerous reptilian remains have been found, notably *Rhynchosaurus*, *Staganolepis*, the earliest known crocodile, and

Telerpeton. A few fish remains occur, including *Palæoniscus, Hybodus,* and *Acrodus.* Among plants several new ferns occur with equisetums, calamites, and conifers, notably *Voltzia;* and cyads are numerous and abundant.

Above the thick series of the Keuper marls there is a comparatively thin layer, averaging, perhaps, about fifty feet in thickness, of dark-bluish shales, and thin light-coloured clayey limestones. In appearance they greatly resemble the rocks of the next system, the Lias, but their fossils are Triassic. They are known as the **Rhætic beds** because they are developed on the flanks of the Rhætic Alps. In England they are sometimes called the "Penarth beds," from Penarth in South Wales. Their special importance is derived from the fact that they contain thin layers, almost entirely composed of broken reptilian bones, fish-scales and teeth; remains of insects allied to the grasshopper, cockroach, and beetle; dwarfed and badly developed shells, especially *Avicula contorta;* and, above all, the teeth and jawbones of a small marsupial, named *Microlestes,* the first appearance of mammalian life. Certain thin marbles, called "landscape marble," from their peculiar marking, are found in these beds near Bristol.

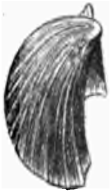


FIG. 206.—*Avicula contorta.*

Among the fishes are the shark-like *Hybodus, Ceratodus,* and *Acrodus,* and many fragments of reptiles, including some of the *Ichthyosaurus* and *Plesiosaurus,* which are destined to become very abundant in the next system.

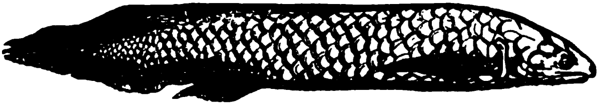


FIG. 207.—*Ceratodus,* a Rhætic fish still living in Australia.

The French and German Trias has been already alluded to. It is remarkable that Triassic beds in such a far distant locality as North America should bear a marked similarity to those of Europe. There is the more or less sudden change of life, the conglomerate, the red colour, the unconformity with the Permian, the abundant rain-pittings, ripple-marks, sun-cracks, and footprints, and they contain the first American mammal, an insectivorous marsupial (*Dromatherium*). In place of salt-beds the Virginian Trias has several beds of workable coal, the result of the abundant vegetable life.

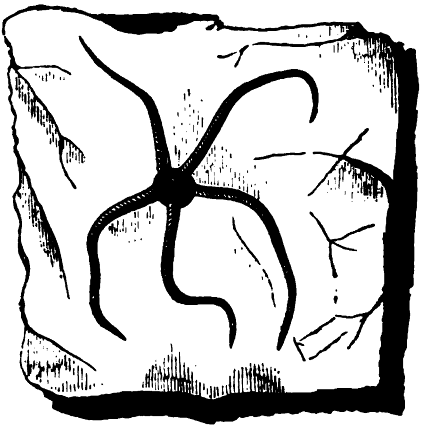


FIG. 208.—A fossil star-fish (*Ophiolepis*) from the Rhætic beds.

In India there are conglomerates, red clays, and grey sandstones, with ferns, labyrinthodonts, and reptiles; and in the Himalayas are beds with a fauna very similar to that of the Rhætic beds. Triassic beds probably occur in Australia, but their fauna is too scanty to rely upon. At the Cape the Trias is represented by some ten thousand feet of sandstones and shales, called the Karoo series. They contain ferns, a conifer, fishes, including a Palæoniscus, amphibians, reptiles, and a small mammal. It is somewhat remarkable that in Europe, in America, and in South Africa, mammals, in every case marsupials, should appear simultaneously, and it suggests a greater uniformity of geographical conditions than prevails at present.

The economic value of the Triassic system is great. In addition to the salt, we get gypsum and alabaster for ornamental purposes, and for the manufacture of plaster of Paris. Gypsum plays an important part in the manufacture of beer, and its presence in the water of Burton-on-Trent has made that town an important centre of the brewing industry. It has been calculated that more than 150 tons of gypsum are imbibed every year by drinkers of Burton beer. The sandstones are well suited for building, and many of them, being rather porous and resting on marls, yield good supplies of water. The marls are used in the manufacture of bricks and terra-cotta.

Summary.—At the end of the Permian period great geographical changes caused such extensive extinction, migration, and modification of the old forms of life, that the line is drawn here between the Palæozoic and Mesozoic groups. The change is more marked in England because most of the Triassic fossils are found in the upper beds at a considerable distance above the Permian strata, but in the Tyrol there are beds containing a mingling of Palæozoic and Mesozoic forms.

THE TRIASSIC SYSTEM.

Scale: 1 inch = 1,000 feet; from 1,000 to 5,000 feet.

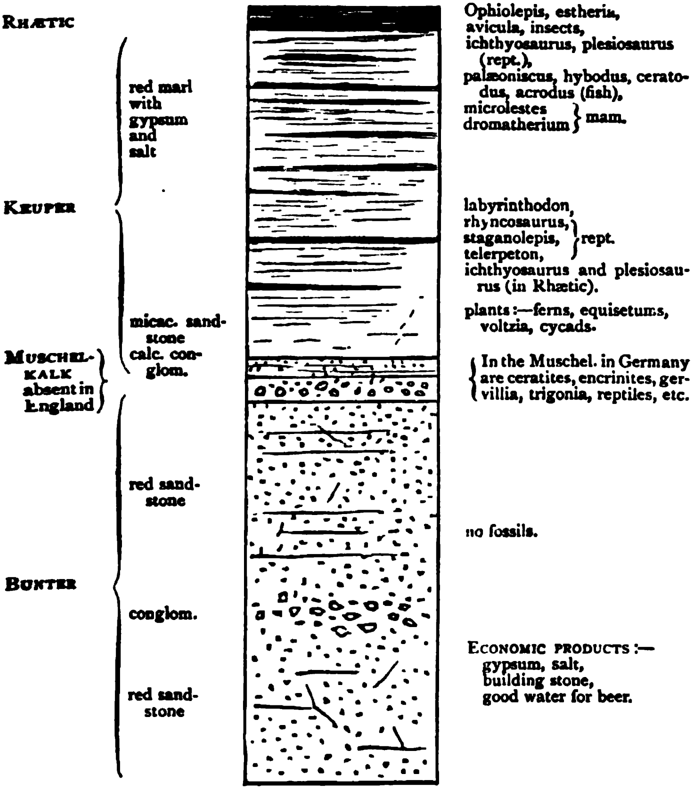

Rhætic
Keuper
Muschel-kalk absent in England
Bunter
red marl with gypsum and salt
micac. sand-stone
calc. con-glom.
red sand-stone
conglom.
red sand-stone
Ophiolepis, estheria, avicula, insects, ichthyosaurus, plesiosaurus (rept.), palæoniscus, hybodus, ceratodus, acrodus (fish), microlestes } mam. dromatherium
labyrinthodon, rhyncosaurus, staganolepis, telerpeton, } rept. ichthyosaurus and plesiosaurus (in Rhætic).
plants:—ferns, equisetums, voltzia, cycads.
In the Muschel. in Germany are ceratites, encrinites, gervillia, trigonia, reptiles, etc.
no fossils.
Economic products:— gypsum, salt, building stone, good water for beer.

Fig. 209.

QUESTIONS.

1. In what respects does the Triassic system (*a*) resemble, (*b*) differ from, the Permian?
2. How is the "Palæontological break" to be accounted for? Is it bridged over anywhere?
3. Explain the meaning of the term *triassic*.
4. Describe and discuss the origin of the conglomerate which lies near the base of the system.
5. What division is absent in England? Describe it and its fossils.
6. Explain the absence of (*a*) the calcium sulphate, and (*b*) the magnesium bromide from most of the salt deposits.
7. What are the chief fossils of the Keuper marls?
8. For what are the Rhætic beds noteworthy?
9. Why is Burton-on-Trent a great centre for brewers?

CHAPTER XXV.

THE JURASSIC SYSTEM.

THE Jurassic system derives its name from the Jura Mountains, where it is well developed, and where beds known as Jura limestone have been long worked. It is very different in appearance from the two New Red Sandstone systems which have preceded. In place of the coarse conglomerates and red sandstones and marls, we now meet with thick dark-coloured clays, and marlstones and limestones, thin and concretionary, or thick and oolitic. The entire system is very conveniently divided in England into two sections, the lower, called the Lias, consisting mainly of very regularly stratified clays, marls, shales, and thin limestones, and the upper, called the Oolite, consisting of thicker oolitic limestones, thick clays, and some sandstones.

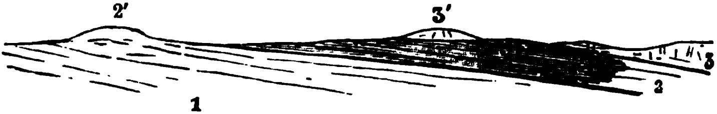


FIG. 210.—Succession of strata from Permian to Oolite in centre of England. 1, Permian; 2, Lias; 2′, Lias outlier on Permian; 3, Oolite; 3′, Oolite outlier on Lias.

(*a*) THE LIAS.

The term *lias*, probably a corruption of "layers," was originally employed by the quarrymen in Somersetshire to denote the thin regularly stratified limestones of the lower Lias. The Liassic strata stretch across England in a narrow strip, slightly curving eastward, from Lyme Regis, on the coast of Dorsetshire, to Whitby and the mouth of the Tees. The width of this Liassic band varies from about a mile in the south of Yorkshire, to about twenty miles in Leicestershire. The strata have a slight dip to the eastward, when they disappear under the Oolite, while the Triassic marls rise from below their western border. Evidence of their further westward extension is found in the scattered outliers, which may be seen at various points, especially in Somersetshire and in the neighbourhood of Bristol, and their presence eastward beneath the Oolites is evident in the river valleys of Northamptonshire, and particularly in the valley of the Esk in Yorkshire, and in its tributary dales.

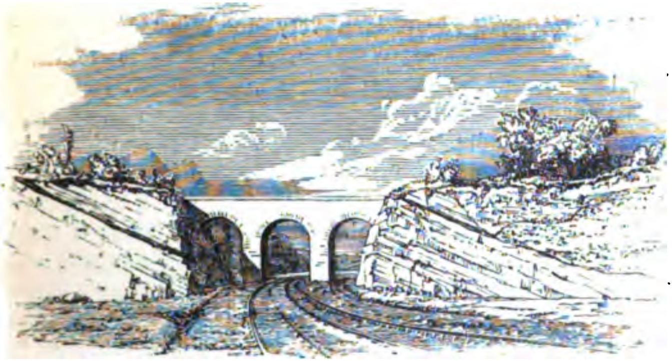


FIG. 211.—A railway cutting in the Lias near Bath. On the left are the Lower Lias beds resting on the Rhætic, on the right the Lower Lias overlaid with recent gravel.

The Lias is divided into three sections, though it is not always possible to say where the line between them is to be drawn. The *Lower Lias* rests directly upon the Rhætic beds, near Cardiff, and in other localities, and consists of several hundred feet of dark shales and clays, with thin but numerous layers of greyish limestones. To the east of Cardiff it rests unconformably upon the Carboniferous limestone, and, as usual in such circumstances, it has at its base a conglomerate formed of the shingle of the old Palæozoic coast.

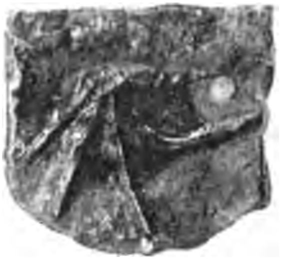


FIG. 212.—*Avicula cygnipes.* Lower Lias. (Jermyn Street Museum.)

The *Middle Lias* consists of clays, marls, and sandstones, with tough clayey limestones in the upper portion, which is called the **Marlstone**, though the name is sometimes given to the whole of the Middle Lias. The marlstone is a very good instance of the variation in thickness and in mineral character which any stratum undergoes if it is traced across a country for any distance. From Dorset to Gloucester it consists largely of clays and sands, and is of considerable thickness. In Oxfordshire it is only about twenty feet thick, but it contains from 15 to 30 per cent. of pure iron, and is now largely worked for that metal. In Cleveland it has a total thickness of 140 feet, and contains sixteen ferruginous layers, the thickest varying from twelve to twenty feet. It presents the appearance of a greenish calcareous sandstone, often both oolitic and fossiliferous, and is largely worked at Eston Nab, and other localities, where it often yields one-third of its weight of iron. The rise of the iron industry in Cleveland dates from 1848, and has been the cause of the conversion of the village of Middlesborough into a large and busy manufacturing town and seaport. The Cleveland ore consists mainly of carbonate of iron mixed with carbonate of lime, clay, and other

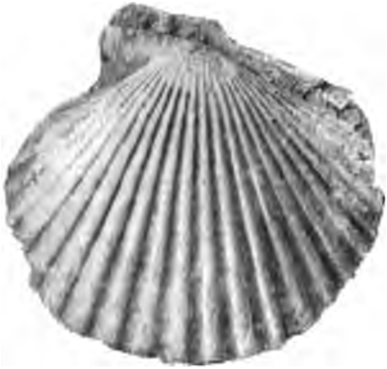


FIG. 213 —*Pecten equivalvus.* Marlstone. (Jermyn Street Museum.)

impurities, and it has been probably formed subsequently to the deposition of the marlstone series. On examining the ironstone beds it may be seen that they contain many shells. Some of these shells are now entirely composed of carbonate of iron, while some are carbonate of lime inside and carbonate of iron outside, while others which are more compact and massive are scarcely altered at all. The rock in which they are embedded contains oolitic grains, which have been similarly altered. There can, therefore, be no doubt that the carbonate of iron has in some way found its way into these clayey fossiliferous bands, and has gradually displaced the carbonate of lime. Iron is a substance which is very widely diffused through nearly all rocks, and no doubt the iron existed in the overlying shales in its usual condition of oxide or hydrate. Decaying organic matter in the shales generating carbonic acid would convert these compounds into carbonate or bicarbonate of iron, which, dissolving in the percolating water, would be brought into contact with the carbonate of lime. Then slowly, molecule by molecule, the iron compound would replace the lime, the carbonate of lime being carried away in solution by the water, and the carbonate of iron being left in its place. No doubt this explanation will apply not only to the Liassic ironstones, but to nearly all others. The Cleveland ironstone, though of a greyish colour in the interior, weathers into a reddish-brown hue. This is due to the conversion of the carbonate of iron into the peroxide.

The *Upper Lias* consists of a succession of clays, marls, and shales, with limestone bands and nodules, the whole varying in thickness from one hundred feet in Dorset and two hundred in Yorkshire, to three hundred in Gloucestershire. The clays are used for bricks, and cement is made from the nodules near Whitby. The shales were once largely used in the manufacture of potash alum, sulphuric acid being obtained by the decomposition of the pyrites present and the oxidation of the liberated sulphur; alumina was derived from the shale, and potash was added. The manufacture of ammonia alum from the coal-measure shales and the ammonia liquor of gasworks has, however, brought the industry to an end, though the Whitby cliffs are still bestrewn with heaps of shaley refuse.

In the Upper Lias in the Whitby district deposits of jet are found filling hollows and crevices between the layers of a few yards of hard bituminous shale. The jet is derived from vegetable matter, sometimes apparently from coniferous wood, in a manner somewhat similar to that in which coal is formed, and sometimes from bituminous matter which has accumulated in recesses in the shale, which is itself in some cases sufficiently bituminous to burn readily. Fossils are also found composed entirely of jet, having undergone a process of replacement analogous to that which has produced the iron fossils in the marlstone.

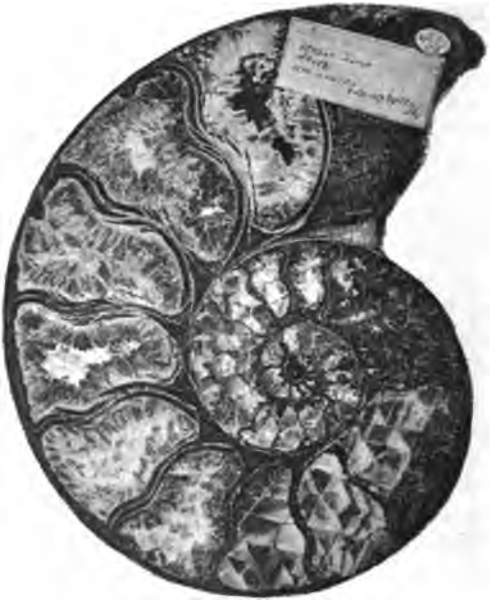


FIG. 214.—Photograph of a polished section of ***Ammonites heterophyllus***, from the Upper Lias. (Jermyn Street Museum.) The siphuncle runs round the outer side of the coil. The chambers are filled with calcite.

In Dorset and Somerset a deposit of sands and calcareous sandstones from one to two hundred feet thick intervenes between the Upper Lias and the oolitic rocks. From their fossil affinities they have been classed as Oolite, but they are now generally regarded as passage beds. They are named **Midford sands** from Midford, near Bath, where they occur, but they are also well displayed on the Dorset coast, near Bridport. In some places they pass gradually into the Lias below; in others, into the Oolite above. A dark calcareous bed in their upper portion has been called the "Cephalopoda bed" on account of the number of Ammonites and other cephalopods which it contains. These sands are conspicuous on the summit of Glastonbury Tor.

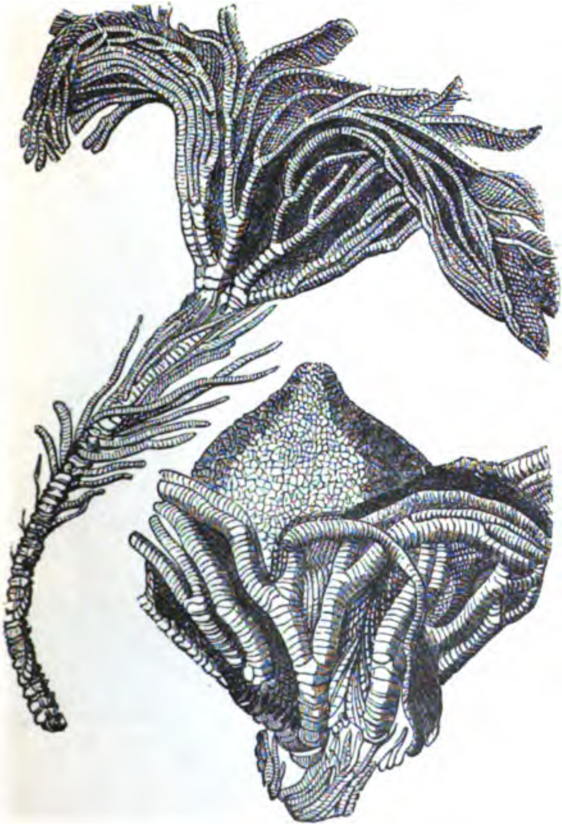


FIG. 215.—*Pentacrinus briareus.*

The general character of the Liassic strata is suggestive of deposition in the shallow water of a large sheltered bay. The coast-line of the period ran in a north-east and south-west direction, a little to the west of the present boundary. From the nature of the strata, the Liassic country is very flat and unbroken, and there are few good natural sections to be seen, except in the cliffs of Whitby and Lyme Regis.

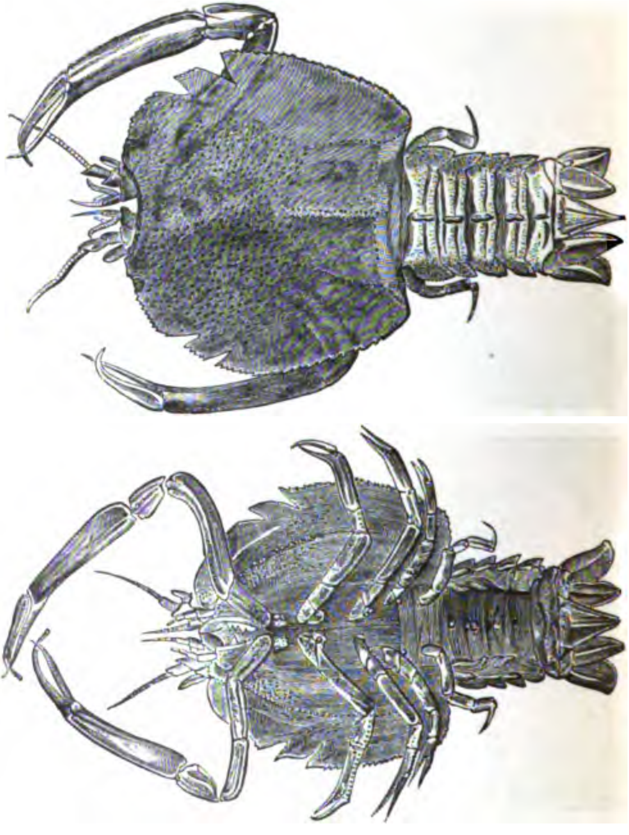


FIG. 216.—*Eryon*, showing under and upper surface.

The Liassic fossils are abundant and characteristic. Plants are not very numerous; the most noticeable are *Cycadites*, *Zamites*, and other cycads, with ferns and coniferous trees.

The shallow and muddy waters were unsuitable for corals, but of echinoderms, *Pentacrinus briareus* (Fig. 215), a stalked form with a large number of branching and many-jointed tentacles, and *Ophiolepis*, a kind of star-fish, are worthy of notice.

Crustaceans have greatly altered. No trilobites and eurypterids are to be found, but forms allied to the lobster and shrimp are common and on the increase. *Eryon* (Fig. 216), a crustacean somewhat like the king-crab, and *Gryphæa*, resembling a lobster, are characteristic. These belong to the tailed group of Decapods (macrourus), the tailless group now represented by the crab (brachyurus) has not yet appeared. Minute crustaceans (ostracods) are abundant. Insects of the dragon-fly and beetle kind are found, especially in the Upper Lias.

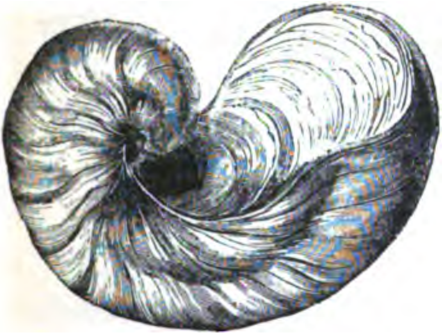


FIG. 217.—*Gryphæa*.

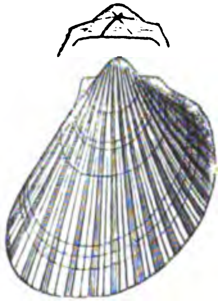


FIG. 218.—*Lima*.

Brachiopods are on the wane. Spirifers appear for the last time, but the genera *Terebratula* and *Rhynchonella*, abundant in Palæozoic rocks, abound also in the Marlstone, and have lived through Mesozoic and Tertiary times to the present day. Of Lamellibranchs, *Gryphæa incurva* is especially abundant and characteristic, and *Lima*, *Modiola*, and *Avicula* may be named.

Cephalopods make an important development by the appearance for the first time of *Ammonites*. The Goniatite of the Palæozoic rocks belongs to the same family, and resembles the Ammonite in its general structure. Like the

Ammonite, it is a coiled shell, consisting of several convolutions and divided into chambers separated by partitions (*septa*) and connected by a tube (*siphuncle*) which passes round the outer, or convex curve of the shell. As a rule the Goniatite is thicker in proportion than the Ammonite, and an important point of difference is the frilled and convoluted edges, or sutures, of the septa, which are seen when the outer coating of shell is removed, and which in the Goniatite are very plain and simple. Another Cephalopod somewhat resembling the Ammonite is the *Nautilus*, which also has a simple suture, but the siphuncle is carried up through the middle of the series of cavities into which the shell is divided. The mouth of the Ammonite shell frequently has projecting portions, while the Nautilus shell is rounded off; and it seems probable that most of the Ammonites were furnished with an *operculum*, or kind of lid, which closed the mouth of the shell and protected the inmate. The Goniatite is exclusively Palæozoic and the Ammonite is exclusively Mesozoic, so that they never occur together. The Nautilus, however, has survived from Silurian times to the present, so that it may occur with either.

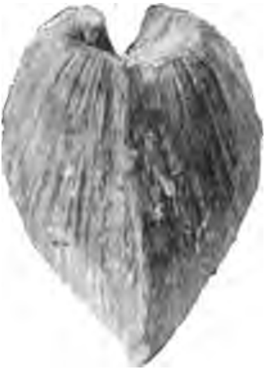


FIG. 219.—*Hippurites ponderosum.* Lower Lias. (Jermyn Street Museum.)

The Ammonites seem to spring into importance at once and attain to a remarkable development. The range in time of many of the species seems to be very narrow, so that it has been possible to divide the Liassic strata into some twelve divisions, or zones, each characterized by and named after its own special and peculiar Ammonite. This particular Ammonite is not always absolutely limited to its own zone, but, if not, it is most abundant in it, so that its presence in any quantity is considered quite sufficient to determine the horizon of the strata in which it occurs. As might be expected, however, it is not always possible to correlate distant beds by this method, and the characteristic ammonites occasionally show a tendency to become a little mixed. It should be observed that the specialization of the study of this genus has led to the formation of subgenera, so that the generic name is often dropped in favour of the name of the subgenus. In the following list the characteristic Ammonites of the English Lias are given, but they are not quite the same for different localities. Specific names only are given, and they are placed in descending order.

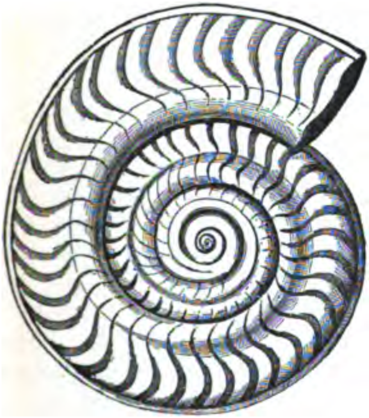


FIG. 220.—*Ammonites bifrons.*

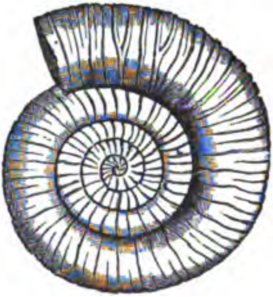


FIG. 221.—*Ammonites communis.*

Upper Lias: Communis, serpentinus.
Middle Lias: Spinatus, margaritatus.
Lower Lias: Capricornus, Jamesoni, armatus, raricostatus, oxynotus, obtusus, Terneri (in S., semicostatus in N.), Bucklandi, angulatus, planorbis.

Of all fossils, those of this group are perhaps the most remarkable for their symmetrical form, their beautiful and distinctive markings, and for the wonderful perfection in which many of them have been preserved. It is not uncommon for them to show the original pearly lustre of the shell; while some have been wholly or partly replaced by iron pyrites, and exhibit a brassy and metallic appearance. Ammonites attracted attention long before geology was seriously studied, and were called "snake stones," under the impression that they were fossilized coiled-up snakes.

Belemnites are also abundant. These are cigar-shaped internal shells of a kind of cuttle-fish. The blunt ends are generally broken off, but are occasionally found perfect, when they are seen to expand into a funnel-like shape, in which a dried-up ink-bag is sometimes found, which was no doubt employed to darken the water as a means of protection and escape, in the same manner as it is used by the cuttle-fish at the present day. The portion ordinarily seen is called the "rostrum," the portion containing the ink-bag the "phragmacone." More than fifty species occur in the Lias, some of them very large.

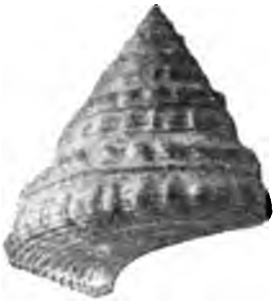


FIG. 222.—*Pleurotomaria rustica.* Lias. (Jermyn Street Museum.)

Shark-like fishes, such as *Hybodus* and *Acrodus*, thrived during the period, and also inflated-looking fishes of the genus *Lepidotus* and *Dapedius*. In all, some hundred and twenty species have been described, many with symmetrical tails of the modern type.

More remarkable and striking than even the Ammonites are the remains of the huge and peculiar reptiles which have been found in the Lias. They seem to have been something between a crocodile and a lizard; some of them were thirty feet long and had paddles like those of a turtle. No doubt they swam freely about in the sea, and fed upon fishes and cuttle-fish, as is proved by the presence of undigested bones, scales, and spines lying within the skeleton in the place where the stomach originally was. They belong to two genera—*Ichthyosaurus* (= fish-lizard) and *Plesiosaurus* (= near to a lizard). (Figs. 225, 226.) The first specimens were found by a lady at Lyme Regis, in the early part of this century, when they were popularly called "sea-dragons." The former resembled a crocodile in appearance, and had very large eyes; the latter was more like a lizard, and had a very long neck. The remains of a peculiar flying reptile, the *Pterodactyl* (= wing-fingered), have also been found.

The useful products of the Lias are iron, jet, limestone, and "marble," cement stone, and clay. The Lias country being damp and heavy, is more suited for grazing than agriculture. Parts of it, however, are well suited for wheat, and some of the Middle Lias soils seem to be well adapted for the growth of cider apples. Some of the lower beds,

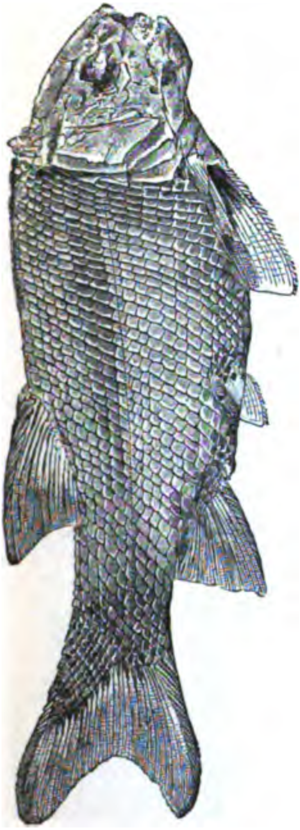


FIG. 223.—*Lepidotus.*

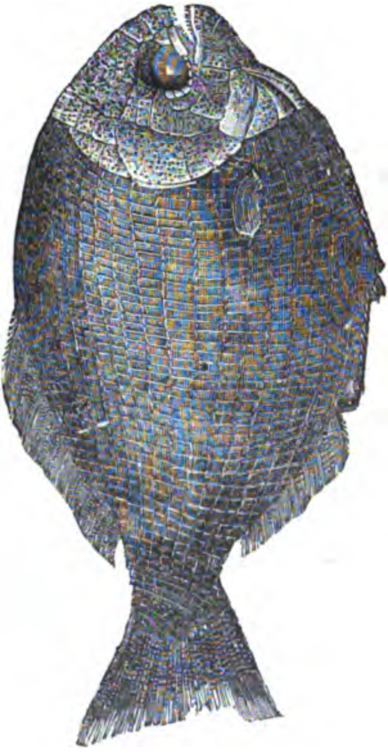


FIG. 224.—*Dapedius.*

situated between the Keuper marls and Lias clays, yield a good supply of water.

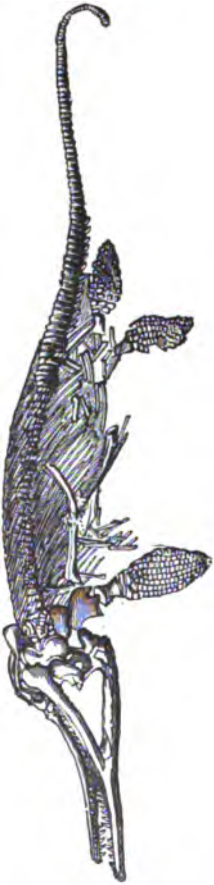


Fig. 225.—*Ichthyosaurus communis.*

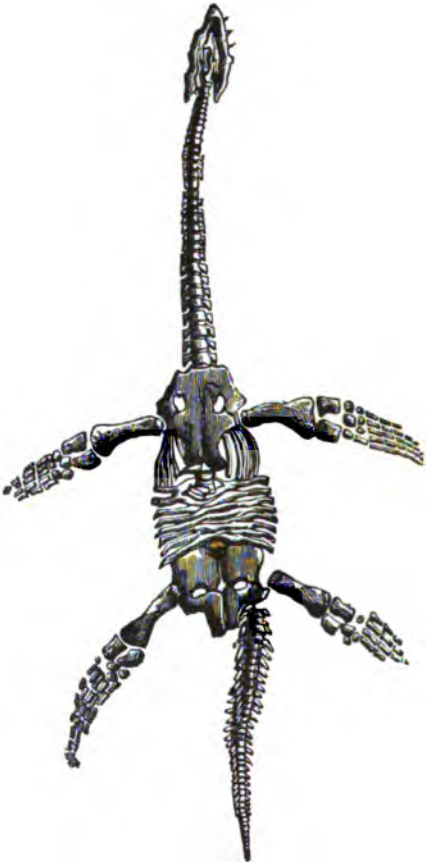


Fig. 226.—*Plesiosaurus Dolichodeirus.* (British Museum—Found in the Lias of Street, near Glastonbury.)

Summary.—The Lias strata offer a marked contrast to the Trias, as regards mineral character and relative abundance of fossils. The most noteworthy stratum is the Marlstone, the most remarkable fossils the ammonites and gigantic reptiles.

THE JURASSIC SYSTEM. (*a*) *Lias.*

Scale: 1 inch = 250 feet; about 1,000 feet.

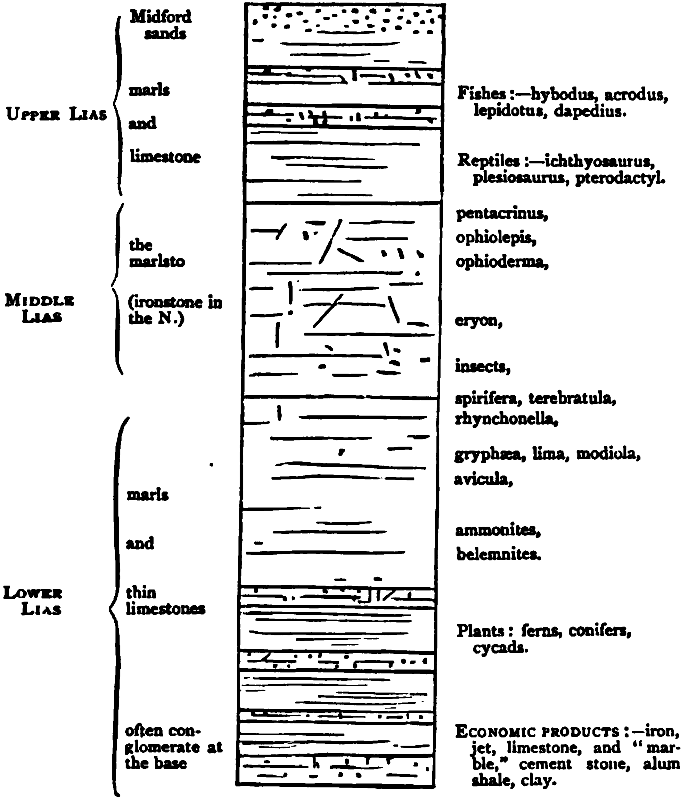

UPPER LIAS
Midford sands
marls and limestone
MIDDLE LIAS
the marlsto (ironstone in the N.)
LOWER LIAS
marls and thin limestones
often conglomerate at the base
Fishes:—hybodus, acrodus, lepidotus, dapedius.
Reptiles:—ichthyosaurus, plesiosaurus, pterodactyl.
pentacrinus,
ophiolepis,
ophioderma,
eryon,
insects,
spirifera, terebratula, rhynchonella,
gryphæa, lima, modiola, avicula,
ammonites,
belemnites.
Plants: ferns, conifers, cycads.
ECONOMIC PRODUCTS:—iron, jet, limestone, and "marble," cement stone, alum shale, clay.

FIG. 227.

QUESTIONS.

1. Contrast the Liassic strata with those of the Trias.
2. Mention any points of interest about the Marlstone.
3. By what chemical process has the Cleveland ironstone probably been formed?
4. Describe the occurrence and probable mode of formation of jet.
5. Give an account of the Midford sands.

6. Describe fully the *Ammonite*. How is it used in the classification of the Liassic strata?
7. Give a description of the *Belemnite*.
8. Describe the Liassic reptiles.
9. What are the agricultural capabilities of the Lias?

CHAPTER XXVI.

THE JURASSIC SYSTEM.

(*b*) THE OOLITE.

THE upper, or Oolitic, division of the Jurassic system may be generally described as a great succession of clays and limestones. The limestones are most of them "oolitic," and give the division its name. They are of various degrees of fineness, and some of them are "rubbly" or "brashy;" that is, they are largely made up of broken and irregular fragments of shells and corals. The Oolitic strata stretch across England over a tract considerably wider than the Lias, and directly to the east of it. The Oolitic, like the Liassic tract, becomes very narrow in the South of Yorkshire, where both divisions are overlaid unconformably by the next system; but it expands in the north-east of the country, and forms the summits of the elevated moorlands which on their southern side are carved into deep valleys by the tributaries of the Derwent, and on their northern side by those of the Esk. In the valleys of these rivers the Oolitic beds have been cut completely through, and the inliers of Lias exposed, which were alluded to in the preceding chapter.

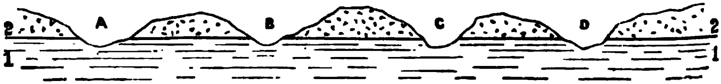


FIG 228.—E. and W. section across the North York moors, intersecting the tributaries of the Derwent. A, Billsdale; B, Bransdale; C, Farndale; D, Rosedale; 1, Lias exposed in the bottoms of the valleys; 2, Oolite.

The Oolites are well displayed in the Dorsetshire and Yorkshire coast sections, and, as the clays and limestones are largely worked for industrial purposes, numerous good artificial sections may also be seen inland. All the Mesozoic strata have, in England, a general dip to the south-east, which causes their upper beds finally to disappear below those of the next system. The alternation of soft and hard beds causes a series of more or less parallel ridges to be formed wherever a clay dips down below its overlying limestone. The direction of these ridges corresponds in a general way with the "strike" of the beds, which is therefore an important factor in determining the physical geography of that part of England. In the lower portion of the Oolites, for example, two thick limestones have in this way formed the Cotswold Hills, which overlook the Liassic plain to the west; and a line of high ground, called the Cliffe, is formed in Lincolnshire by the equivalents of the same beds. In all cases like these, where a line of hill is formed by a hard stratum resting on a softer one, the steep face of the hill or the escarpment overlooks the lower stratum, and the more gradual slope on the other side generally coincides with the dip of the harder bed, and is called the "dip slope."

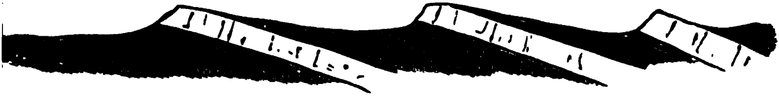


FIG. 229.—Effect on the landscape of gently dipping beds of oolitic shales and limestones.

This alternation of beds of clay and limestone is also important in connection with water-supply. Clay is impervious; limestone is very pervious to water. The rain, soaking into the limestone at its outcrop, finds its way downwards and saturates the whole stratum. The under- and overlying clays keep the water pent up, ready to issue forth wherever it can find an opening. The occurrence of springs of water along the line of junction of pervious and impervious strata has had a great influence in the distribution of population, and in originally determining the position of villages and towns. The various springs which give origin to the Thames arise in this way in the Cotswold Hills.

The study of the Oolitic beds in detail makes very clear the fact that, however thick, distinct, and well-marked strata may be in one part of the country, yet they do not maintain their character for any great distance; massive limestones gradually changing into sand, and thick clays thinning out and disappearing altogether. This, of course, is due to the varying geographical conditions under which they were deposited. Indeed, a comparison of the Yorkshire Oolites with those of the south suggests the idea that the water was much shallower in the former locality, and formed a portion of a great estuary.

The Oolites are divided into Upper, Middle, and Lower, each of these divisions consisting of several formations or series. The names given to the latter are derived from their southern English localities, where they were either first studied and described, or where they are best shown. Indeed, some of them thin out and disappear in the middle of England, or take on such a different aspect that it is difficult to correlate them.

The divisions of the Oolite as ordinarily given are as follows:—

Upper ...	Purbeck beds,
	Portland beds,
	Kimmeridge clay.
Middle ...	Coralline oolite,
	Oxford clay,
	Kelloways rock.
Lower	Cornbrash,
	Bradford clay and Forest marble,
	Great oolite and Stonesfield slate,
	Fuller's earth,
	Inferior oolite.

The lower Oolite is most fully developed in the south, where it attains a thickness of about five hundred feet, and consists of three limestones and two beds of clay. (*a*) The lowest of the series is the **Inferior Oolite**, which consists of oolitic limestones, rubbly beds, and marls. The finer limestones are good building-stones; they work equally well in all directions ("freestones"), and they have the very convenient and valuable property of being comparatively soft and

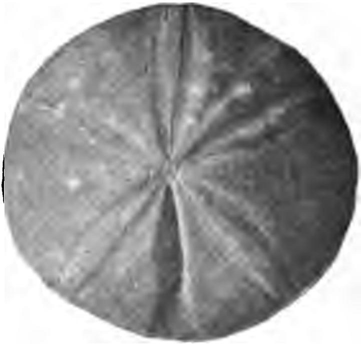


FIG. 230.—*Clypæus Plotii.* Inferior Oolite. Jermyn Street Museum.)

easily sawn when newly got from the quarry, and of hardening by exposure. This series illustrates the way in which strata gradually change their character. Near Bridport in Dorset, where, it may be noted, the Midford sands are very thick, they are represented by about fifteen feet of limestone, while in the Cotswolds they are 240 feet thick. In Northamptonshire they are largely represented by a series of estuarine and marine sands which, except a few fossils, have nothing in common with the Cotswold beds. The lower part of these sands is rich in carbonate of iron, which is largely worked.

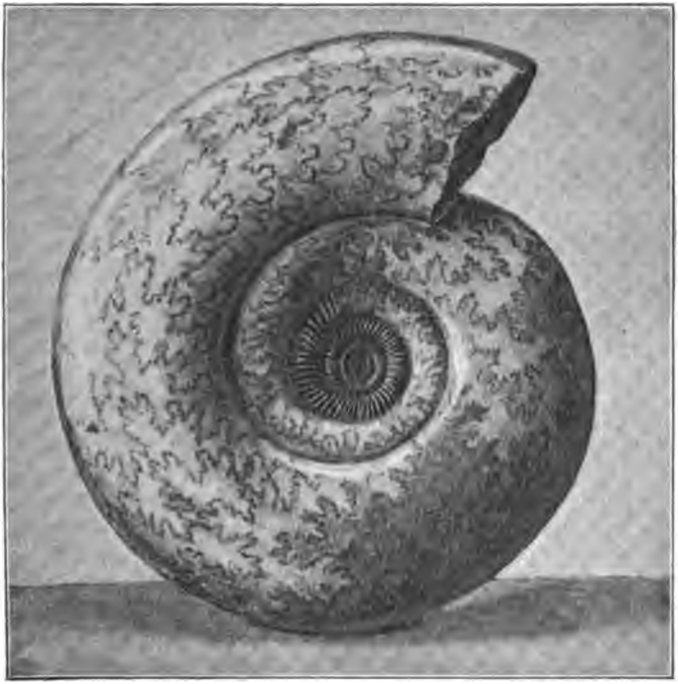


FIG. 231.—Photograph of a polished specimen of *A. Dorsetensis* from the Inferior Oolite of Sherborne. The shelly covering is removed from the outer coils in order to show the frilled edges of the septa. (Jermyn Street Museum.)

The Inferior Oolite is in places very fossiliferous. Perhaps the most familiar fossils are the *trigonias*, a lamellibranch genus, exclusively Mesozoic, of which this division contains thirty species. Of Ammonites the chief are, *Parkinsoni* in the upper, and *Humphresianus* in the lower. Belemnites are also abundant. There are also found sponges, corals (*Isastræa*), echinoderms (*cidaris* and *clypeus*). Various species of *Rhynchonella* and *Terebratula* abound and Saurian bones are found.

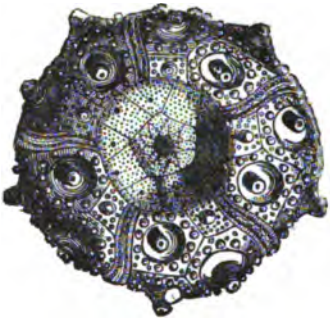


FIG. 232.—*Cidaris.*

Above the Inferior Oolite is the **Fuller's earth** series, containing limestones more or less marly, and beds of fuller's earth, some of value, others not. The good veins are either blue or yellow, and range in thickness up to four feet. The material consists roughly of three parts clay and one part carbonate of lime, and is valuable on account of its remarkable power of absorbing grease. Other clays are used for bricks. Like most clay soils, that of the fuller's earth is wet and heavy, and, owing to its greasy nature, much addicted to slipping. The series thins off rapidly from south to north; being four hundred feet thick in Dorsetshire, one hundred and fifty near Bath, and disappearing entirely in the north. Fossils are rare, and no fish or reptilian remains have been found.

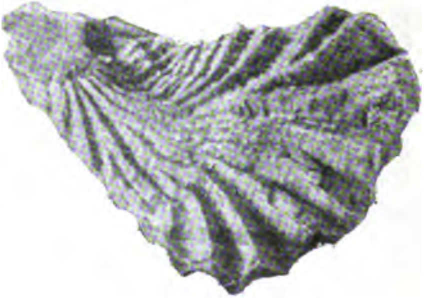


FIG. 233.—*Ostræa flabelloides.* Inferior Oolite. (Jermyn Street Museum.)

The **Great Oolite** is a series of limestones varying much in character. Some of the beds make excellent building-stone, known as Bath stone, and much used in Bath and London. Some of the beds are very fossiliferous, being very rich in mollusca, though poor in ammonites and other cephalopods. In Oxfordshire, in the lower part of the series, occur the **Stonesfield Slates**, consisting of laminated sandy limestones, used locally for roofing. These "slates" are interesting geologically on account of their fossils, especially four small species of marsupials belonging to the genera *Amphitherium*, *Phascalotherium*, and *Stereognathus*, ranging from the size of a rat to the size of a rabbit. For some time, until the discovery and investigation of the Rhætic beds, these were the oldest known mammals. They seem to have been part of a fauna and flora analogous to that found in Australia when it was discovered, and the remains seem to have been brought from neighbouring land and deposited in the still waters of a lagoon. The plant-remains, which are abundant, indicate a luxurious growth of tree ferns, cycads, and conifers, many being very large and well grown, and suggestive of a warm and favourable climate. Mollusks and insects are also found with the bones, scales, and palatal or crushing teeth of fishes. Very noteworthy also in these and some other Oolitic formations are various members of an order (*Pterosauria*) of flying reptiles, which first appear in the Lias, and which are characteristic of and confined to the Mesozoic era. The Stonesfield representative is called the *Rhamphorhynchus*. These creatures had light and hollow bones like birds, and, unlike the existing so-called flying reptiles, did not merely use their wings like a parachute to assist them in taking leaps, but actually flew like a bat.

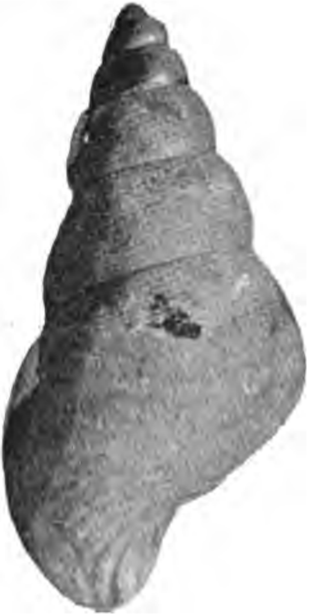


FIG. 234.—*Phasianella striata*; Kimmeridge clay; Weymouth. Figured by Strangways. (Jermyn Street Museum.)

In the Great Oolite the first remains of tortoises and of other terrestrial or semi-terrestrial reptiles are met with. One genus (*Teleosaurus*) of these represents the crocodiles of the period. They were evidently of predaceous habits, their long beak-like mouths bearing a very extensive set of pointed teeth. Smooth oval bodies found in the same strata are believed to represent their eggs. Another reptile was the *Megalosaurus*, twenty-five to thirty feet long; and a still larger one was the *Cetiosaurus* ("whale-lizard"), a collection of whose remains, in a very crushed and disorganized condition, were recovered from a quarry near Oxford and pieced together. An examination of these remains, and others which have been found, suggest a huge lizard ten feet high and more than forty feet long!

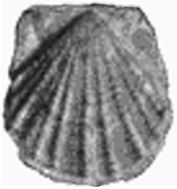


FIG. 235.—*Pecten peregrinus.* Great Oolite. Fig. Pal. Soc. (Jermyn Street Museum.)

(*d*) The **Bradford clay** occurs near Bradford, in Wiltshire. It is comparatively thin, but contains in its lower beds numerous specimens of the "pear encrinite," *Apiocrinus*, locally known as "peg-tops," also from their shape. The lower ends of the stalks stand in the position of growth on the underlying limestone, and their heads and sections of their broken stalks ("coach-wheels") are scattered through the lower portion of the clay. This suggests that after the formation of the limestone the water remained clear for a time before the deposition of the clay, and it has been observed that some of these encrinites bear on them the calcareous cases of *serpulæ*, and that the serpulæ are themselves encrusted with *polyzoa.* These organisms could not have taken up their abode upon them after they were buried in mud, so that the evidence for a period of clear water is strengthened.

In Oxfordshire this clay is partly represented by beds of a rubbly fossiliferous limestone containing a few hard shelly bands, which have been worked in Wychwood Forest for ornamental purposes, and which go by the name of *Forest Marble.* Some of them are used as flags for roofing, and their upper surfaces often exhibit very perfect and well-preserved examples of ripple-marks, worm-tracks, and crustacean and reptilian footprints.

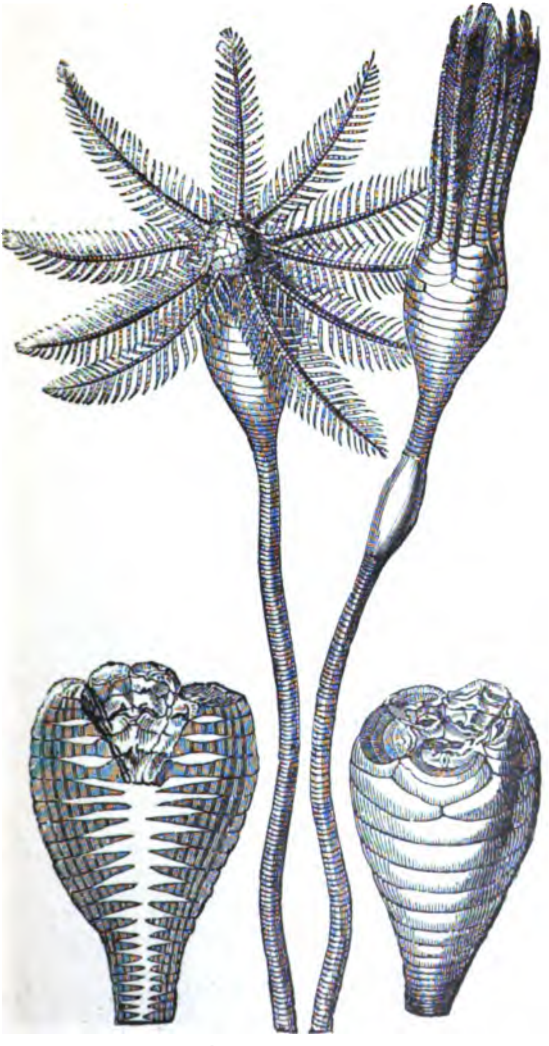


FIG. 236.—Pear encrinite (*Apiocrinus*).

(*c*) The **Cornbrash** is a lumpy and rubbly oolite, thin, but, unlike some of the thicker beds, remarkably constant, being recognizable throughout the whole oolitic tract from Dorset to Yorkshire. It derives its name from the fact that when disintegrated it is well suited for corn-growing, probably on account of the presence in it of phosphate of lime. It is fossiliferous, but the fossils, owing to the nature of the rock, are not well preserved.

The **Middle Oolite** consists of two calcareous beds separated by a thick clay.

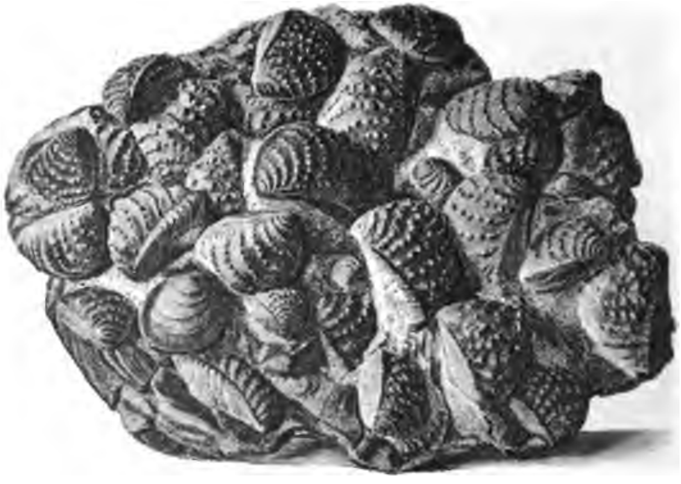


FIG. 237.—A mass of *Trigonia clavellata* from the coral rag near Weymouth. (Jermyn Street Museum.) The other shell is a *Lucina*.

(*a*) The **Kellaways Rock** is a sandy limestone, which becomes thicker as it is followed northward. It is fossiliferous, especially near Chippenham, and contains forty-one species of ammonites, among them *A. Jason*, while the Cornbrash below it has only one.

(*b*) The **Oxford clay** is a dark blue, tenaceous, limy clay, reaching a thickness of five hundred feet. Like most clays, it contains iron-pyrites and selenite, and it is largely used for brick-making. In the south it is very bituminous. Brachiopods and Lamellibranchs are rare, though *Gryphæa dilatata* is common; but Cephalopods, especially *Ammonites* and *Belemnites*, occur in a remarkable state of preservation. The latter, both here and in the Kellaways rock, is found with phragmacone and ink-bag perfect, and even exhibits impressions of the tentacles. Remains of the great reptiles are also found.

(*c*) The **Coralline Oolite** is a very variable series, but, as a rule, it consists of calcareous grits and clays above and below, with limestones in the middle. The latter are generally composed of rough fragments of shells and numerous corals, and are known as "rag-stone" or *Coral rag*. These corals, among them *Isastræa* and *Thecosmilia*, are the last reef-builders which occur in the English geological series. A *Cidaris* and other echinoderms are well preserved, and the series has also yielded the fruit of a cycad and fir-cones.

The **Upper Oolite** consists of clay below and limestones above.

(*a*) The **Kimmeridge clay** is named from a village on the Dorset coast, where the clay may be well seen in the cliff. In this locality it is about five hundred feet thick, but it varies greatly in different places. In the south its upper beds are most largely developed, in the north its lower. In Dorset it is very bituminous, so much so as to be often used as fuel. It also contains pyrites, and on the Dorset coast the oxidation of the pyrites often generates sufficient heat to ignite the bituminous shales. The clay contains also thin limestones, calcareous nodules, and selenite, and is very fossiliferous, its saurians being both numerous and large, notably *Pliosaurus*, a large swimming reptile, and an *Iguanodon*. In all it has yielded forty species of Reptiles and thirty Ammonites.

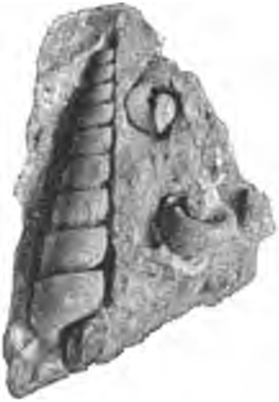


FIG. 238.—*Cerithium Portlandicum*, internal cast. (Jermyn Street Museum.)

(*b*) The **Portland beds** consist of sand and marls below and limestone above. The limestone, under the name of Portland stone, is largely used in building. At Portland it is about sixty feet thick, and consists of a white shelly oolitic limestone. The Portland beds yield specimens of *Ammonites giganteus*, often four feet in diameter, and locally known as "conger eels," and numerous casts of a gasteropod, *Cerithium Portlandicum*, commonly called the "Portland screw" (Fig. 238). *Trigonia gibbosa* is also characteristic.

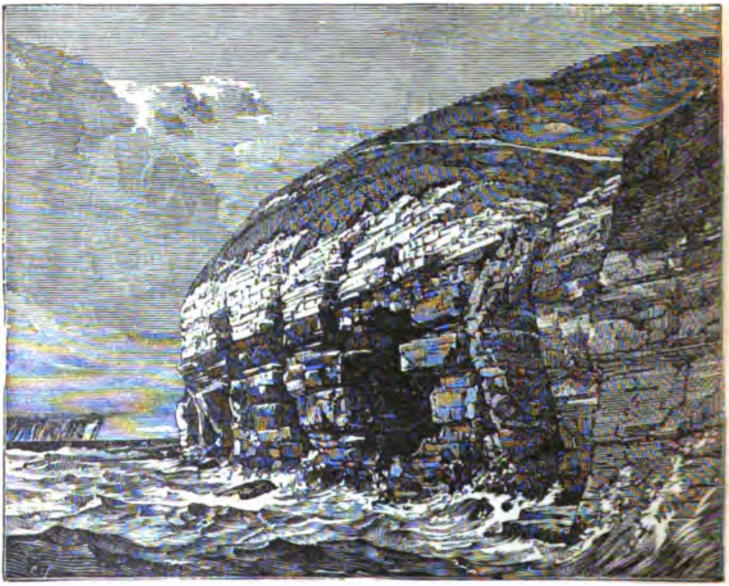


FIG. 239.—Section near Swanage. Purbeck beds (light coloured) resting on Portland beds.

(*c*) The **Purbeck beds** exhibit unmistakable signs of estuarine deposition. The limestones are clayey, and many of them are studded with the remains of a small fresh-water snail, *Paludina*. These stones are known as *Purbeck marble*, and were in great favour in the Middle Ages with the builders of our cathedrals and churches, who used them for the shafts of many of the slender clustered pillars. They may be readily recognized by their brown colour, and by the above-named shells, which appear as lighter-coloured spots on the surface of the stone. A proof of occasional dry land appears in the presence of dark clay bands known as "dirt beds." These are, no doubt, ancient soils, analogous to the underclays of the coal measures or to those in which the submerged forests of our coasts are rooted at the present day. They contain silicified roots and trunks of trees, and in some of them an extraordinary assortment of *insects* has been collected, insects allied to the cricket, cockroach, aphis, dragon-fly, ant, and beetle, the total number of species found being about one hundred. *Reptiles* also occur, including specimens of turtles, crocodiles, and lizards; and, again, a collection of from twenty to thirty species of small insect-eating *marsupials.* Besides *Paludina*, the limestones contain other fresh-water shells, such as *Limnæa* and *Planorbis*, and marine shells are absent. In the centre of the series, however, there is evidence of a return for a time to marine conditions, for there we find shelly limestones containing *Ostrea* (oyster), *Pecten*, and *Avicula*.

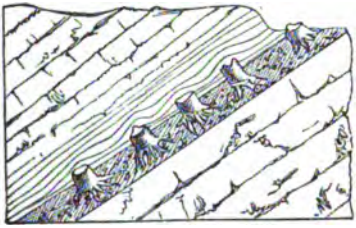


FIG. 240.—"Dirt bed" in the Purbeck beds, with roots.

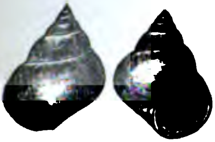


FIG. 241.—*Paludina.*

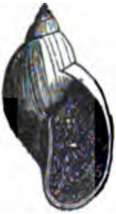


FIG. 242.—*Limnæa.*

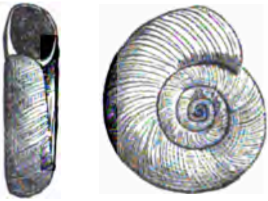


FIG. 243.—*Planorbis.*

The shallow-water character of the Yorkshire Oolites has been already alluded to. There the strata consist chiefly of sandy clays, sands, and sandstones, with two or three thin seams of inferior coal. As in the coal measures, these coal seams are associated with ironstone bands, and the whole series is suggestive of an abortive attempt to restore the Carboniferous period, though the plant-remains are very dif-

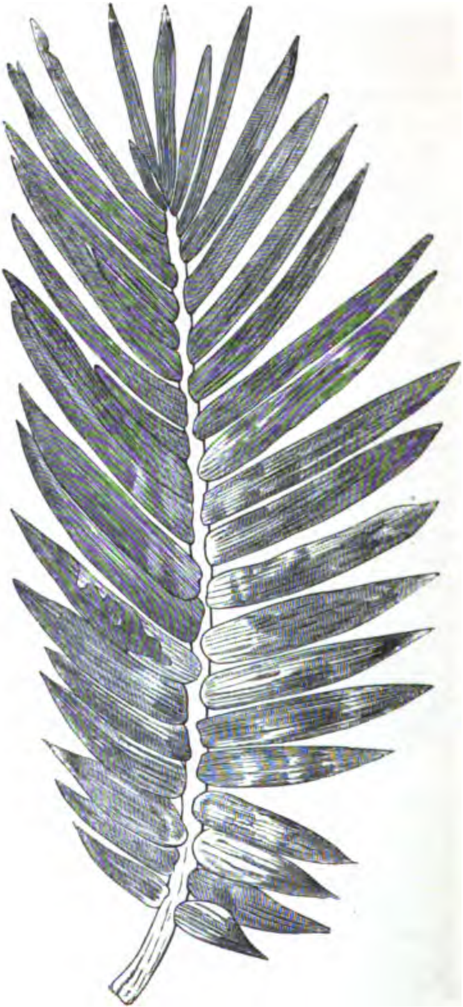


Fig. 244.--Leaf of *Zamia* (a cycad)

ferent. Still further north, at Brora in Sutherlandshire, is a distant outlier of the Oolite containing a seam of very fair coal, more than a yard thick, which has been much worked. It seems, therefore, that during Oolitic times there was deep water to the southward, gradually shallowing towards a coast-line in the north; and that, as time went on, even in the south, partly from the large amount of deposition, and partly, probably, from elevation, the sea became shallow, and in places dry land appeared. As to climate, the great reptiles, ferns, cycads, and marsupials indicate at least a somewhat higher temperature than we enjoy at present; but the Purbeck insects do not suggest tropical conditions, but rather temperate. Although the strata of the Lias and Oolite bear evidence to changes of depth, yet the uniformity with which the series follow each other, and the absence of contemporary igneous rocks, inform us that a period of comparative repose had followed the disturbances which brought the Palæozoic era to an end.

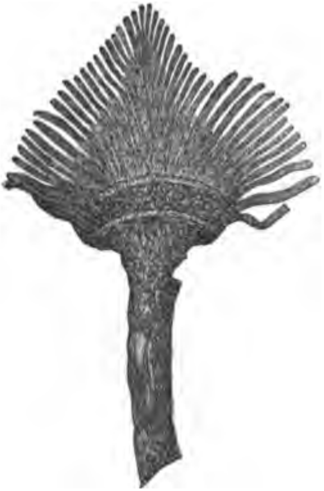


FIG. 245.—Flower-spike of cycad from the oolitic rocks.

The Jurassic system of the continent of Europe agrees remarkably with that of England. In the Jura Mountains it has been thrown into folds by subsequent disturbances, and denudation has brought the whole series of beds into view, the Liassic strata being best exhibited on the French side, and the Oolitic on the Swiss. In the north-east of France the great Wealden anticlinal has brought up and exposed to denudation, in addition to older rocks, a complete series of the Oolitic strata; and both Lias and Oolite are exposed in Normandy and through Central to Southern France. In central France a thick and valuable bed of ironstone occurs in the Upper Lias; and in

Normandy the well-known Caen Stone is a member of the Great Oolite. The Lias also occurs in the Carpathians, where it contains two or three workable beds of coal, with beds of iron ore.

The most-noted Oolitic beds, however, of the Continent are the lithographic limestones of Solenhofen, in Bavaria, which are equivalent in age to the English Kimmeridge clay. These are extremely fine-grained and evenly laminated, and are not only absolutely indispensable to the lithographer, but are geologically interesting for the variety and perfect preservation of their fossils, the wings of insects, the tentacles of cuttlefish, the antennæ of crustaceans, and the scales of fishes being preserved in the most striking manner. Of these fossils, the most remarkable is the earliest-known bird, the *Archæopteryx*, which, like most early forms, exhibits a remarkable admixture of the characters of two or more classes. This first bird exhibits several points of likeness to reptiles. It has a tail with vertebræ, or joints, like a lizard, but on each vertebra there are two feathers. It has teeth in its jaws, and claws on each wing. Two specimens have been discovered in the Solenhofen beds, and are the only ones known. Very perfect skeletons of the flying reptiles *Pterodactyl* and *Rhamphorhynchus* have also been found in these beds.

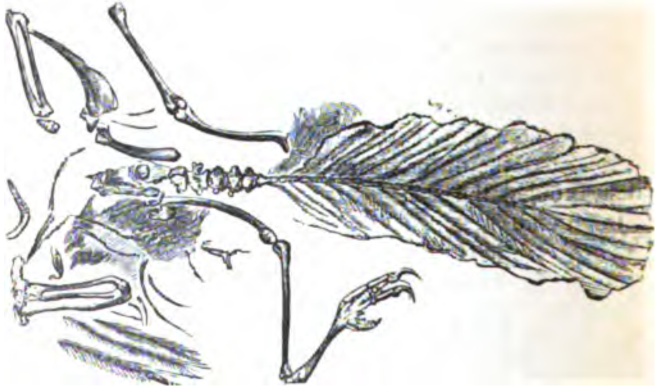


FIG. 246.—Fragments of the *Archæopteryx*.

In India the Jurassic series is very complete and recognizable, but not the Lias. Some of the carbonaceous shales contain coal. The system is also represented in Australia, New Zealand, and the Cape: but, as might be expected, the resemblances to the English strata are not great; and though ferns, ammonites, and belemnites, and various molluscan genera formed in the Jurassic system in Europe occur, there is no record, so far, of the gigantic reptiles. In America, however, it is otherwise; for, from fresh-water beds of Jurassic age in the Western States, remains of huge reptiles, exceeding in size those of Europe, have been found. Such are the *Atlantosaurus* and *Brontosaurus.* The latter is calculated to have been fifty feet long, and to have made footprints a square yard in area.

The economic products of the Jurassic system are building-stone, clay for bricks, iron in Northamptonshire, and a small quantity of inferior coal.

From the agricultural point of view, the clays, especially the Oxford clay, are adhesive and difficult to work, and are generally devoted to pasture. Near the outcrop of the calcareous beds a good soil is formed by the admixture, suitable for arable land. Many of the strata of the Lower Oolite form good corn-land. Springs of water are abundant, though there are localities, especially on the Oxford clay, where water is difficult to obtain, and not always of good quality.

SUMMARY.—The Oolitic system consists of alternations of thick clays and limestones, generally oolitic and sometimes brashy. The latter make conspicuous escarpments, and have an important bearing on the water-supply, and hence on the distribution of population. Some of the beds are very changeable, while others are remarkably constant over large areas. From the palæontological point of view, the most interesting formations are the Stonesfield slates and the Purbeck beds in England, and the Solenhofen stone in Germany.

QUESTIONS.

1. What are the general characters of the Oolitic rocks?
2. Give examples of (*a*) the constancy and (*b*) inconstancy in character of some of the formations.
3. Describe the geological formation of the Cotswold Hills.

THE JURASSIC SYSTEM. (*b*) *Oolite.*

Scale: 1 inch = 500 feet; about 2,500 feet.

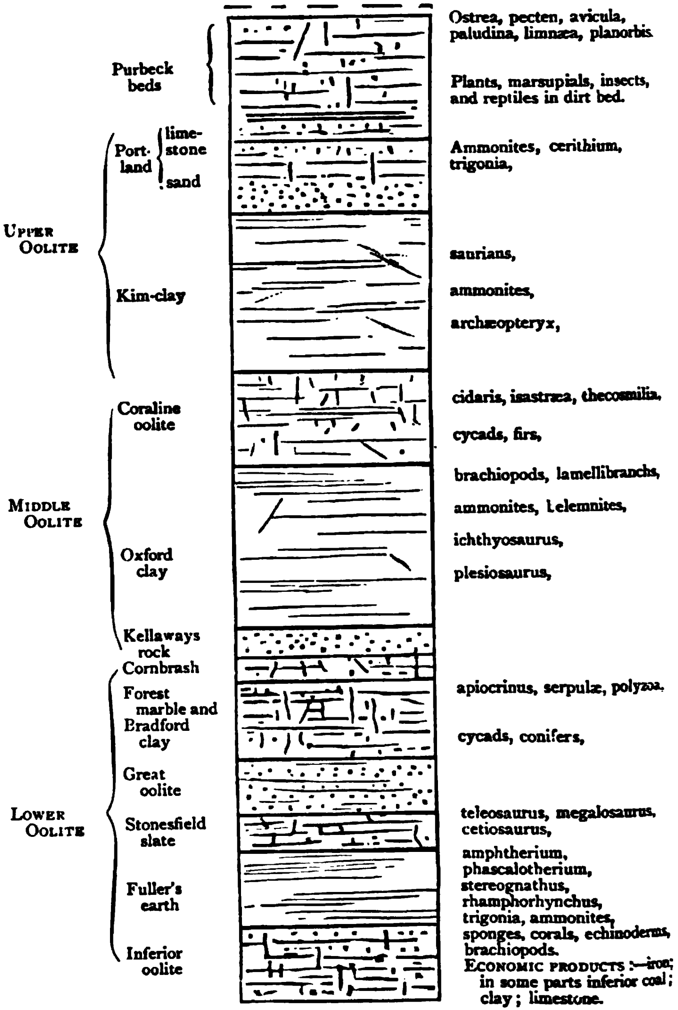

Upper Oolite
Purbeck beds
Port-land
lime-stone
sand
Kim-clay
Middle Oolite
Coraline oolite
Oxford clay
Kellaways rock
Lower Oolite
Cornbrash
Forest marble and Bradford clay
Great oolite
Stonesfield slate
Fuller's earth
Inferior oolite
Ostrea, pecten, avicula, paludina, limnæa, planorbis
Plants, marsupials, insects, and reptiles in dirt bed.
Ammonites, cerithium, trigonia,
saurians,
ammonites,
archæopteryx,
cidaris, isastræa, thecosmilia,
cycads, firs,
brachiopods, lamellibranchs,
ammonites, belemnites,
ichthyosaurus,
plesiosaurus,
apiocrinus, serpulæ, polyzoa,
cycads, conifers,
teleosaurus, megalosaurus, cetiosaurus,
amphtherium, phascalotherium, stereognathus, rhamphorhynchus, trigonia, ammonites, sponges, corals, echinoderms, brachiopods.
Economic products:—iron; in some parts inferior coal; clay; limestone.

Fig. 247.

4. Illustrate, by reference to the Oolitic system, the way in which the distribution and industries of the people are affected by geological conditions.

5. Describe some Oolitic building-stones, and say what formations they are obtained from.

6. For what are the Stonefield slates remarkable?

7. What noteworthy reptiles have been obtained from the Oolitic rocks, and from what formations?

8. Classify the following fossils, and name the Oolitic formations from which they have been obtained: *Isastræa*, *Phascalotherium*, *Cerithium*, *Planorbis*, *Clypeus*, *Cetiosaurus*, *Trigonia*.

9. Describe the Kimmeridge clay.

10. What are the Purbeck "dirt-beds"? Describe their fossils.

CHAPTER XXVII.

THE CRETACEOUS SYSTEM.

THE Cretaceous system derives its name from the fact that in Europe its most characteristic member is the chalk (Lat. *creta*). The system consists of a series of clays, sands, or sandstones, with thin limestones below, and a thick mass of white chalk above. The chalk is by far the most noticeable formation, and its escarpment may readily be traced across the country in a line roughly parallel to and a little to the east of the outcrop of the Oolites. The whole system has, like the other Mesozoic systems, a general but very gentle dip to the south-east; but, in addition to this, it has, since its deposition, undergone a considerable amount of bending into anticlinal and synclinal folds. It bends downwards under London and the lower Thames valley, and also in the southern part of Hampshire, forming what are known as the "London Basin" and the "Hampshire Basin," and in both these areas it is covered by later formations. Between these two depressions, however, there is a broad anticlinal, which, in its western portion, forms a great spread of chalk, which includes Salisbury Plain and the Marlborough Downs; while in the east, in the Weald of Kent and Sussex, the top of the bend has been denuded away, in all probability by the sea, and the beds of the lower portion of the system exposed to view.

In the Hampshire area the chalk, after dipping down under

Southampton, rises rather abruptly in the Isle of Wight, forming the east and west ridge, which runs across the island. Here, in the same manner as in the Weald, but on a smaller scale, the top layer of chalk has been worn through by denudation.

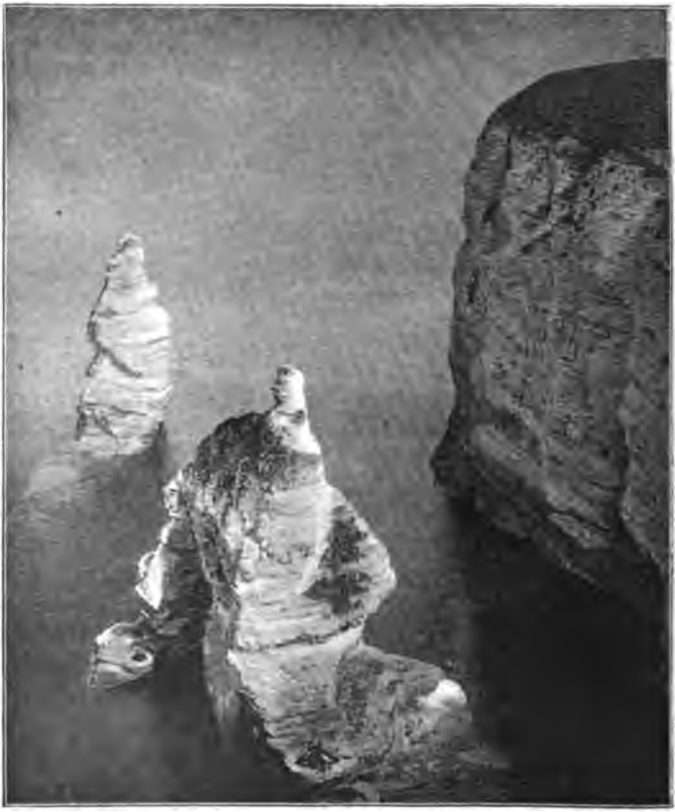


FIG. 248.—Chalk cliffs of Flanborough; The "King and Queen." (Wilson.)

We have seen that in the south of England the Oolitic period terminated with shallow-water conditions when the estuarine and fresh-water deposits of the Purbeck area were laid down. This continued, and at the same time the slow elevation converted other portions of the Oolitic area into dry land, as is proved by the fact that the bottom beds of the Cretaceous system are made up largely of their waste, including rolled and water-worn specimens of Oolitic ammonites.

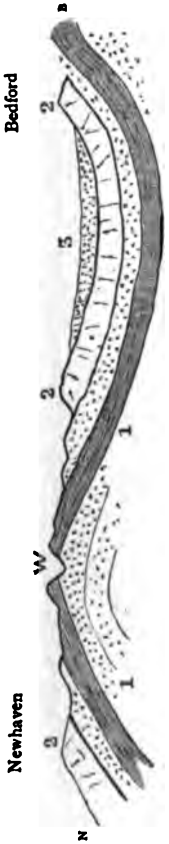


FIG. 249.—Section from Newhaven (N) to Bedford (B).
1, Lower Cretaceous; 2, Chalk; 3, Tertiary; (W) Weald.

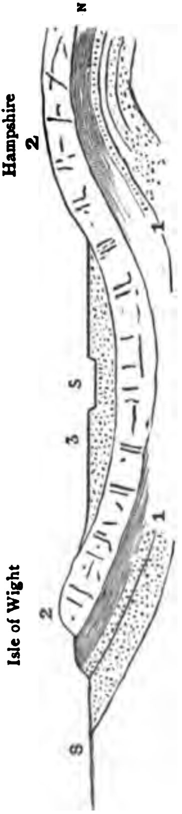


FIG. 250.—N. and S. section through the Isle of Wight and Hampshire
1, Lower Cretaceous; 2, Chalk; 3, Tertiary; S, Spithead.

The Cretaceous System is divided into an upper and a lower division. The lower division, in the south of England, may be again subdivided, the bottom half consisting of fresh-water sands and clays, and the upper of marine sands and clays. The fresh-water deposits constitute the *Wealden series,* so named because they are well developed and displayed in the Weald. They are distinctly fresh-water, but this was due only to local conditions, their representatives northward, in Yorkshire, and southward, in Belgium and Switzerland, being marine. These English Wealden strata were accumulated either in a lake or in the estuary of a great river flowing from the north-east. The northern shore of this area was formed by a Palæozoic tract which at that time formed dry land along the south of what is now the Thames estuary, and which still exists as an underground ridge, deeply buried by later deposits. The Lower Cretaceous rocks have been proved by deep-well borings to gradually thin out and disappear as they approach this ridge, which may be regarded as a proof that in Lower Cretaceous times it was dry land; and this opinion is strengthened by the fact that there are pebbles of Palæozoic rock in these lower beds. The Wealden series consists of two divisions.

(*a*) The **Hastings sands** are alternately beds of sand and sandstone and mottled clay. The sands are ferruginous, and yield water containing salts of iron (chalybeate water) at Tunbridge Wells. In some of the sandstones iron is very abundant, and there are bands of clay-ironstone in the clays. In olden times this iron was largely worked, and smelted with wood from the great forest of the Weald; but as wood grew scarce, and coal came more and more into use for iron smelting, the Sussex iron-works ceased to be profitable, and the industry came to an end in the early part of the present century. Like the Whitby alum works, it has left behind it heaps of refuse which may still be identified. In the iron-bearing strata there is also the usual association of carbonaceous deposits in the shape of bands of lignite or imperfectly-formed coal.

(*b*) The **Weald clay** rests upon these sands. It is of a pale grey colour, and upwards of one thousand feet thick. It contains a few bands of shelly limestone, some of which are rendered ornamental by the fossils of two kinds of *Paludina* (*fluviorum* and *sussexiensis*), and are known according to the localities where they occur, as Sussex, Petworth, or Bethersden "marble." They are not unlike the Purbeck stone, and have

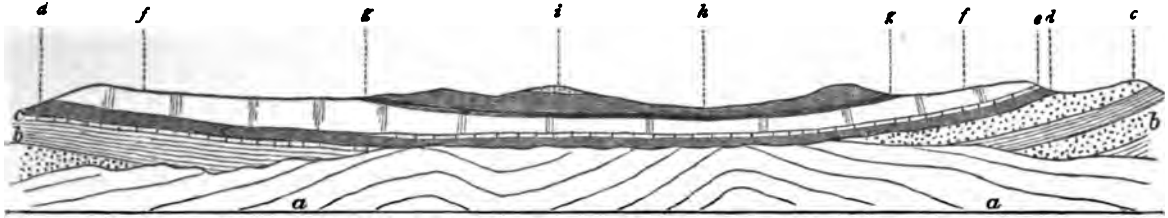


FIG. 251.—Cretaceous (*b* to *f*) and Tertiary strata (*g*, *h*, *i*) resting on the Palæozoic ridge (*a*) in the London basin. *b*, Oolite and Wealden; *c*, Lower Greensand; *d*, Gault; *e*, Upper Greensand; *f*, Chalk; *g*, Lower Tertiaries; *h*, London clay; *i*, Bagshot beds.

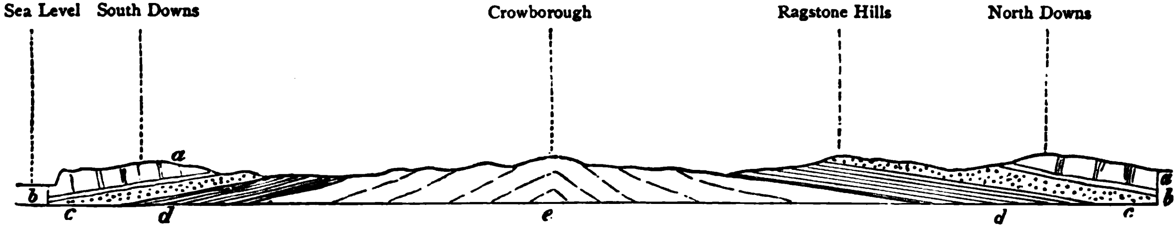


FIG. 252.—N. and S. section across the Weald. *a*, Chalk; *b*, Gault and Upper Greensand; *c*, Lower Greensand; *d*, Weald clay; *e*, Hastings beds.

been used locally for similar purposes. There are also here and there in the Weald clay one or two thin water-bearing sands.

These two divisions of the Wealden series, one sandy and the other clayey, impart their special features to the country. The country where the former comes to the surface is hilly and diversified, while the Weald clay area is flat and more or less damp and water-logged. It is traversed by the railway between Reigate and Ashford, and the general flatness of the country is illustrated by the fact that this line, some forty-five miles in length, is quite straight.

The Wealden fossils are distinctly fresh-water or terrestrial. They consist of well-known fresh-water genera of shells, as *Paludina*, *Melanopsis*, *Cyrena*, *Unio*, and a genus of small fresh-water crustaceans, named *Cypris*, which is very abundant. In addition, there are trunks, twigs, leaves, and cones of pines and cycads, and fronds of ferns, no doubt brought down and submerged in time of flood. But the most remarkable fossils are the *Iguanodon*, an enormous vegetable-eating lizard discovered in the Hastings sands, and first described by Dr. Mantell; and the *Hylæosaurus*, a kind of spiny-backed crocodile.

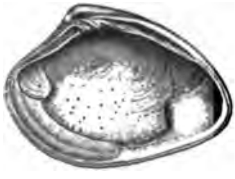


FIG. 253.—*Unio.*

These Wealden beds may also be seen in the Dorsetshire coast, near Swanage (Punfield beds), and on the east and west coasts of the southern portion of the Isle of Wight, where they are brought up by the anticlinal previously mentioned. In these localities they consist of very variable sands and clays, but while the series in the Isle of Wight is wholly or largely freshwater, that at Swanage contains marine fossils, such as species of *Cerithium*, *Cardium*, *Ammonites*, and others.

Except in the north-east of France and in Belgium, where there is a continuation of the English Wealden strata, the lower cretaceous beds of the Continent are marine. They occur in Switzerland, where, under the name of *Neocomian*, they are very fully developed and fossiliferous, and form a complete series extending from the top of the Oolite to the

Upper Cretaceous. On the Yorkshire coast north of Flamborough there is a thick marine clay which Professor Judd has shown to correspond with the Upper Oolite and Lower Cretaceous of the south. The top half of this clay contains fossil species of Ammonites, *Astierianus*, *Exogyra*, *Ancyloceras*, and others similar to those of the Swiss Neocomian.

When there are two deposits which cannot be proved to be stratigraphically continuous, the one containing marine fossils, the other land and fresh-water, it is difficult to say whether they were deposited contemporaneously or not; and this problem presents itself in the case of the Neocomian, including the upper Speeton clay, and the Wealden. The Dorsetshire Punfield beds, however, are not far off the Wealden series, especially from those of the Isle of Wight, with which they were undoubtedly once continuous; and Professor Judd is satisfied that they are synchronous with the upper part of the Wealden. At the same time they contain lower Neocomian fossils. Therefore we conclude that the upper part of the Wealden, at any rate, is also synchronous with the Lower Neocomian.

These correlations are set forth in the following table:—

Wealden Area.	Isle of Wight.	Dorsetshire.	Yorkshire.		Switzerland.
Lower Greensand	Sandstones Atherfield clay	Lower Greensand	Upper Middle	Divisions of the upper half of the Speeton clay	Neocomian
Weald clay Hastings beds	Wealden beds	Punfield beds	Lower		

Resting on the Weald clay are the beds of the **Lower Greensand**, containing a large assortment of salt-water shells. We must, therefore, suppose that a subsidence of considerable extent occurred, for not only was a fresh-water or estuarine region converted into sea, but we find that the deposits of that sea were much more widespread than those of the preceding epoch. The Lower Greensand not only rests on the Wealden beds, but overlaps them, and rests unconformably on the older systems to the westward, some outlying patches of it being found, even in Devonshire, resting on Palæozoic strata.

This formation takes its name from the fact that some of its sands have a dark green colour, owing to the presence of tiny grains of a green mineral called *glauconite*, and even where they are too few to impart colour scattered grains may often be detected. Many of these glauconitic grains, perhaps all of them, are internal casts of foraminifera. The shells have been filled with glauconite in the same manner as many larger shells are filled with carbonate of lime, quartz, or pyrites; the next stage in the process is the gradual removal by solution of the delicate shells, by which the glauconitic casts are left; these casts, washing to and fro with the sand, become rubbed down often beyond recognition, and supply the characteristic dark green grains.

The Lower Greensand series in the Wealden area consists of the following fairly well-marked subdivisions, the oldest being given last:—

Folkestone beds: sands often light-coloured, with indurated ferruginous layers.

Sandgate beds: variable sands and clays, with sandstones in places, and fuller's earth near Reigate.

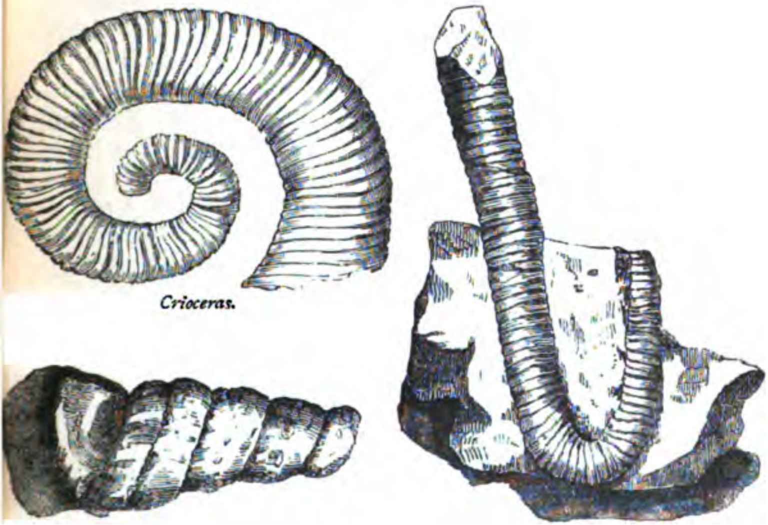
Hythe beds: sands and layers of calcareous sandstone known as *Kentish Rag*, largely worked near Maidstone.

Atherfield clay, a dark clay, with thin bands of limestone.

The best sections of the Lower Greensand may be seen on the coast of Kent in the neighbourhood of Folkestone, and in the Isle of Wight. The variable nature of the strata, consisting of clays, sands, sandstones, and limestones, causes the Lower Greensand country to be very hilly and picturesque, culminating, perhaps, in the region known as the Surrey Hills to the south of the chalk escarpment between Dorking and Farnham. In this neighbourhood Leith Hill and Hindhead rise upwards of one thousand feet above the sea, and considerably overtop the North Downs.

The Lower Greensand is an important water-bearing series. It is very permeable itself, and has impermeable clays both above and below it. It sinks down under London, and has a large outcrop to the north and south, where the water is collected and saturates the whole mass. This water, which is soft and fairly pure, is tapped by many artesian wells in London and North Kent.

The fossils, though not numerous, are distinctly marine, and comprise Brachiopods such as *Terebratula sella*, Lamellibranchs such as *Exogyra sinuata* and *Perna Mulleti*, with Ammonites (*Deshayesii*), Nautilus, Fishes, and *Iguanodon* and other Wealden reptiles. Remains of coniferous trees are also preserved, including cones of cedars, which appear to have been more varied then than now.



Crioceras.

Turrilites. *Hamites.*

FIG. 254.—A group to illustrate the variation in the Ammonite family during the cretaceous period.

The upper division of the Cretaceous system comprises sedimentary beds of clay and sand, with the chalk resting upon them.

(*a*) The **Gault** is a blue marly clay, with limestone concretions and phosphatic nodules, the latter being worked, near Cambridge, for manure. The gault is very fossiliferous, although many of its fossils fall to pieces as they dry. Ammonites are both numerous and distinctive, and many have so narrow a range that, mainly by their means, palæontologists are able to divide the gault into eleven zones. Among characteristic species may be mentioned *mamillare*, *interruptus*, *lautus*, and *splendens*. Many of the ammonites begin at this period to vary very widely from the type, and to assume strange forms, some being partly (*Crioceras*) or wholly (*Baculites*) uncoiled, some hooked (*Hamites* and *Scaphites*), some drawn out in spirals (*Turrilites*). (Fig. 254.) Other noteworthy fossils are various species of *Terebratula*, *Inoceramus* (*concentricus* and *sulcatus*), *Pecten*, *Avicula*, and *Belemnites*.

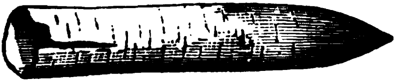


FIG. 255.—A *Belemnite*.

The Gault does not preserve its special character to a very great distance: it is sandy in the Isle of Wight; and northward, as exhibited near Hunstanton, on the Norfolk, and near Filey, on the Yorkshire coast, it is represented, at any rate in part, by a remarkable band of red clayey chalk, known as the *Red Chalk*. In the Wealden region the gault is used for bricks and pottery, and is very important in connection with water-supply, as it forms an impermeable stratum between the porous chalk and the Lower Greensand. This brings out the water in a line of springs on the lower slope of the Downs, a line which may be traced in Kent by a series of ancient villages and small towns which skirt the foot of the North Downs, such as Wrotham, Deptling, Thornham, Hollingbourn, Harrietsham, Lenham, Charing, etc.

(*b*) The **Upper Greensand**, where well developed, consists of light-coloured sands and soft sandstones with the characteristic glauconite grains. It is thin or absent in the eastern part of the Weald, but thickens to the west and north-west, being 25 feet thick at Eastbourne under the South Downs, and at Godstone under the North Downs, near Petersfield it is 80 feet, and in the Isle of Wight 150 feet thick. Sponge fossils, especially a stalked form called *Siphonia*, are numerous.

(*c*) The **Chalk** is no doubt the best known and most readily recognized of all the English geological formations. It ranges inland across the country from Dorchester to King's Lynn, through the east of Lincolnshire, and the south-east of Yorkshire. Along this line of country it forms the high ground of the Marlborough Downs, the Chiltern Hills, and the Lincolnshire and Yorkshire Wolds, while the two escarpments which overlook the Weald form the North and South Downs. These chalk hills afford a good illustration of the way in which many of our minor hill ranges are formed; and they also show that the presence of very hard rock, though it may be necessary in the formation of mountain systems, is not essential to the formation of these escarpment hill ranges, the only condition being that the escarpment-forming stratum shall be a little harder than its neighbours. In this case the chalk, though one of our softest limestones, forms well marked features, because it happens to have a thick bed of easily denuded clay below it, and loose sands above.

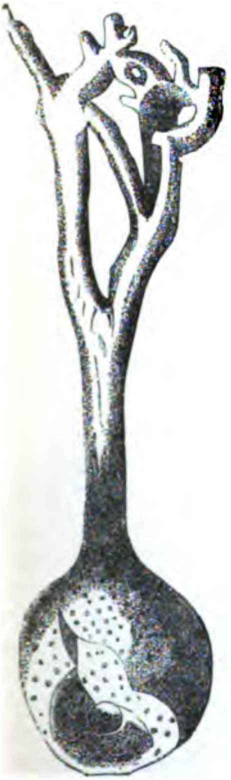


FIG. 256.—*Siphonia pyriformis.*

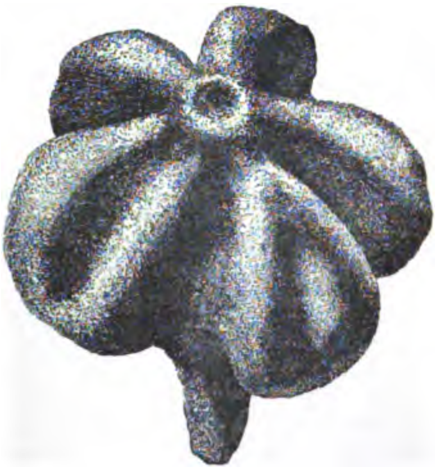


FIG. 257.—*Siphonia costata.*

The chalk may be described as a soft, powdery, porous limestone, much jointed, and readily yielding to atmospheric agencies. In composition it is somewhat variable, but when purest it contains, after drying, about 98 per cent. of carbonate of lime, the remainder being silica, clay, and other substances.

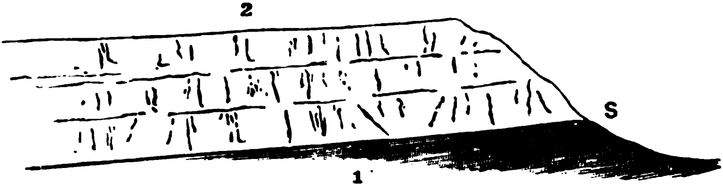


FIG. 258.—Chalk (2) resting on the gault clay (1).
S. position of the springs along the foot of the escarpment.

The carbonate of lime is almost entirely shelly material of some kind; some specimens are large and readily recognized, others are either very minute or fragmentary. The small shells are mainly foraminifera, and may be frequently detected by examining under the microscope, either a very thin slice of chalk, or some very fine chalk powder. The thickness of the chalk varies in different parts of the country from 600 to 1000

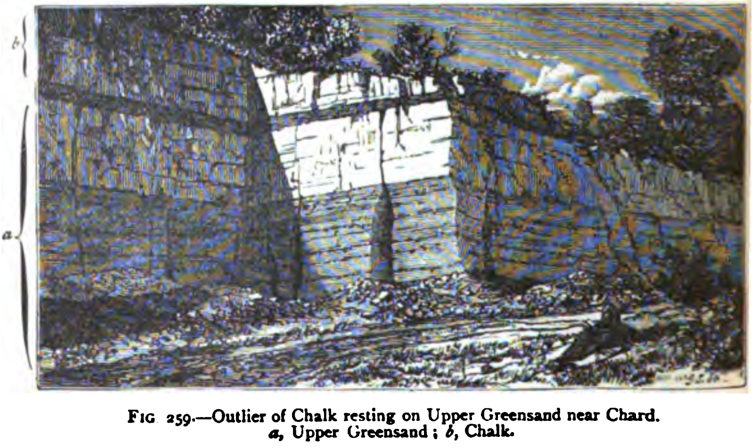


FIG 259.—Outlier of Chalk resting on Upper Greensand near Chard.
a, Upper Greensand; *b*, Chalk.

feet. It is very permeable to water, easily allowing the rain which falls upon it to sink into it. This water is largely used for domestic purposes: it contains a large quantity of dissolved carbonate of lime (16 or 18 grains per gallon), and is consequently very "hard," but in other respects pure and satisfactory. The surface of the chalk is generally covered with a thin soil, which consists for the most part of the insoluble residue of the chalk after the carbonate of lime has been carried away in solution. Owing to the fractured condition and porous nature of the chalk, it is generally quite destitute of streams except those which, flowing from other strata, make their way across it towards the sea

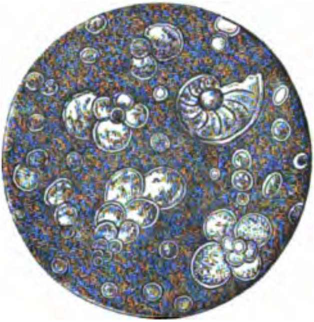


FIG. 260.—Section of Gravesend Chalk.

The chalk is worked in immense quantities for burning into lime, and for making cement. Lime-making is carried on all over the chalk area; cement-making has its headquarters in North Kent, where the old muds of the Thames and Medway are utilized.

Between the Upper Greensand and the lowest beds of the chalk there occurs, in the Isle of Wight and other localities, a bed of more or less compact marl, with the usual glauconitic grains. This is called the *Chloritic marl*, and though raised to the dignity of a subdivision or "zone," it may probably in most cases be regarded as either Upper Greensand or Chalk.

The chalk formation is divided into three sections, viz.—

(3) Chalk with Flints.
(2) Chalk without Flints.
(1) Chalk-marl.

(1) The *Chalk-marl* is a grey-coloured, very clayey and impure chalk, containing in its lower portion only about 70 or 80 per cent. of carbonate of lime. It contains phosphatic and pyritic nodules, and is sufficiently tenaceous and impermeable to stop the further descent of the great bulk of the chalk water. As it passes upward it becomes purer and purer, and passes into—

(2) The *Chalk without Flints*. This forms the central mass of the chalk. The lower portion is intermediate in character

between the chalk-marl and the pure white chalk, and is called the *Grey Chalk.* In its upper portion it contains scattered flints, and even a few layers of them. Like the beds above, it is much shattered and broken, and allows a ready passage to water, not only through its substance, but through the joints and cracks. Frequently in the course of digging deep wells large cavities full of water are broken into. These, like the caverns in the harder limestones, have no doubt been formed in the course of ages by the solvent action of water.

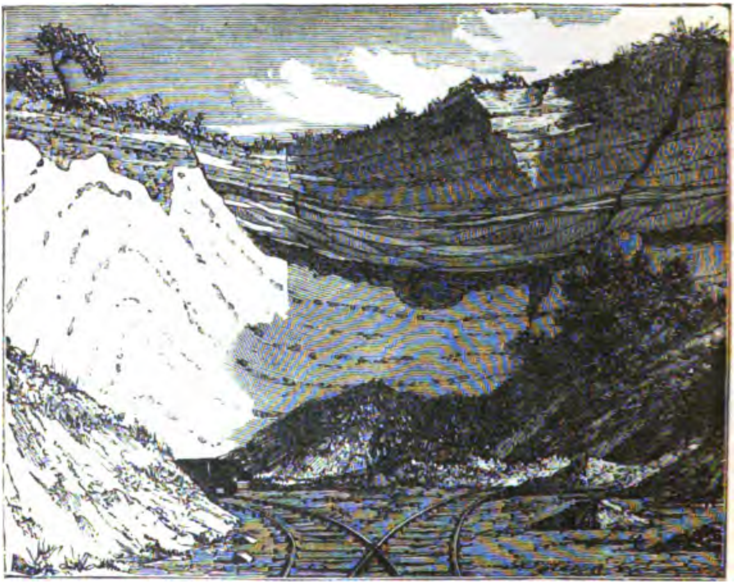


FIG. 261.—Contorted chalk with Tertiary strata resting unconformably upon it. Whitlingham, near Norwich

(3) The *Chalk with Flints.* This is so called from the characteristic rows of flints which lie between its strata. The origin of these flints has been the subject of much discussion. In considering the question it is necessary to remember that the flint occurs in the chalk in several positions. The horizontal layers are the best known. They consist generally of detached, irregular, more or less flat masses of flint, varying considerably

in size. Sometimes the masses are united into an almost continuous layer, and some are layers of flint only one or two inches thick, which often possess an agate-like structure, very suggestive of having been deposited from chemical solution. At the very top of the chalk, interposed between it and the overlying sands of the next system, is a layer of flints coloured a dark green colour on the outside, and often embedded in a layer of ordinary flint, which has evidently been formed after the flints which it encloses. Vertical and oblique cracks in the chalk are also filled with flat sheets of flint. It is obvious, therefore, that much at least of the flint has been formed by chemical deposition since the chalk was formed. In addition to the layers and plates, flints occur scattered through the chalk in an irregular fashion, and these more especially frequently contain fossils, round which, and often in which, the

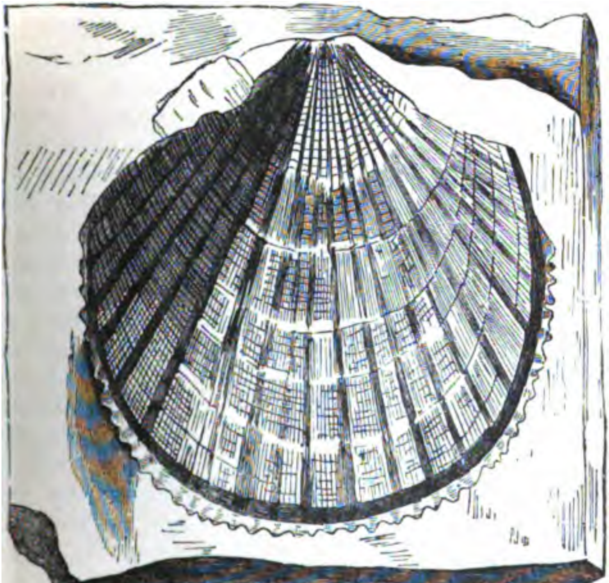


FIG. 262.—A Bivalve shell, *Pecten*, from the Greensand.

flint seems to have been deposited. We may therefore reasonably conclude that the flints have been formed by chemical action, in a manner somewhat similar to the layers of ironstone and calcareous nodules in other rocks. Other limestones besides the chalk contain siliceous layers and masses, known as *chert*, but, as the chert is nearly the same colour as the limestone, it is not so noticeable. The source of the flint was probably within the chalk itself. Flinty sponges were common, and their scattered spicules are very abundant, especially in the chalk without flints. Silica, in a more or less soluble form, also exists in these lower beds, but not in the upper. It, therefore, looks as if the scattered flinty material had been gradually collected by the percolating water, and converted into flints in the upper beds, but not in the lower. As flint in solution has a tendency to deposit itself on other flinty masses, it would naturally aggregate round any flinty sponges or other organisms which had not been dissolved, or, failing them, round other fossils. Possibly, also, flint may have been brought down in solution from overlying sands. The flints are used for road-mending, building, and are ground up for use in the manufacture of china and glass, and for glazing pottery. They were very important to prehistoric and uncivilized man, being almost exclusively used, wherever they could be got, for his implements and weapons. Many of the

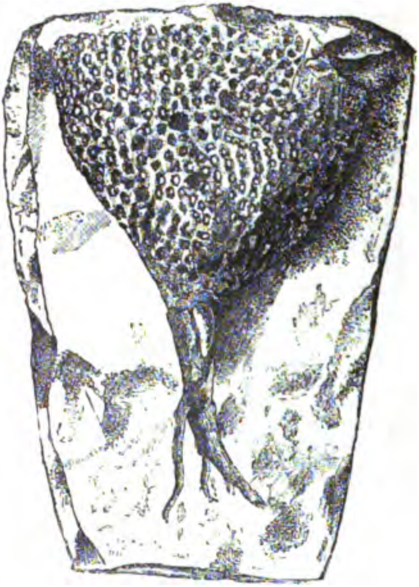


FIG. 263.—*Ventriculite.*

old churches in the Chalk districts are built partly or wholly of flints, and in some cases show specimens of elaborate chequer and inlaid work. Many of the flints are found to contain fossil sponges, some ramifying irregularly, and forming large shapeless masses, and some, cup or pear-shaped in form, contained in flints resembling themselves in shape, and rounded and smooth on the outside. One of the latter is *Ventriculites*, which with the others also occurs without any flint as a reddish brown stain in the chalk. Foraminiferæ are abundant in the chalk, most of them of comparatively shallow-water genera. The best known are *Globigerina* and *Rotalina.* (Fig. 265.) The corals are not of the reef-building kind, where large numbers form a huge stony mass, but are of the single detached kind, such as *Parasmilia* and *Caryophyllia*, which as a rule live in deeper water.

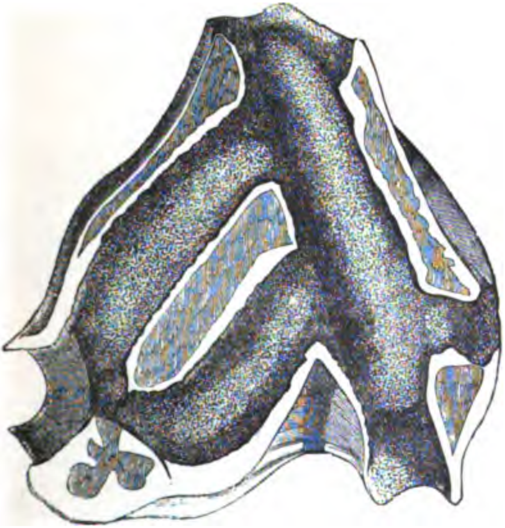
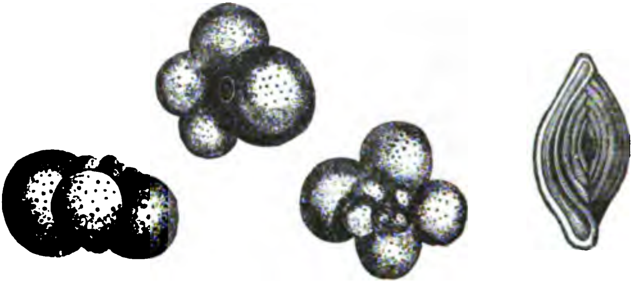
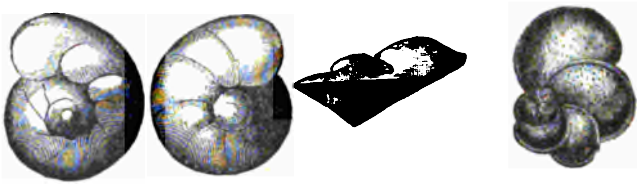


FIG. 264.—A branching sponge in flint.

Echinoderms are very abundant, and reached their greatest development at this epoch. They form the most noticeable and characteristic tossils of the chalk. Many are of great beauty and symmetry, being ornamented with knobs, tubercles,



Globigerina. *Spiroculina.*



Rotalina.

FIG. 265.—Foraminifera common in the chalk.

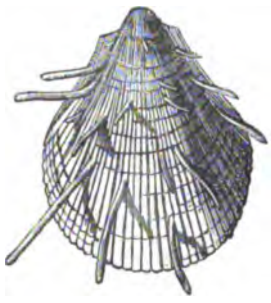
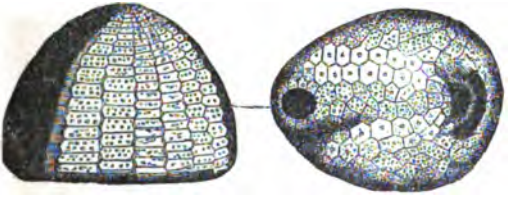


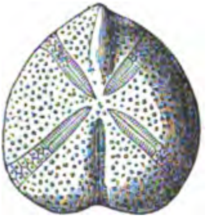
FIG. 266.—*Spondylus.*

and punctures, arranged in geometrical patterns, and having often highly decorated and club-shaped spines. *Cidaris sceptrifera* and *Cyphosoma Kœnigi* are of this latter kind. *Galerites albogalerus*, *Ananchytes ovatus*, and *Micraster cor-anguinum* are also both common and characteristic. *Marsupites*, resembling an encrinite without a stalk, is also noteworthy. Many of these, as well as other fossils, have polyzoa ramified over their surfaces, together with serpula cases, a fact which illustrates the slow rate at which they were buried under the accumulating chalk. New species of old brachiopod genera are found, such as *Terebratula carnea* and *T. striata.* Of Lamellibranchs, perhaps the most characteristic are a species of *Spondylus* (*spinosus*), which had long spines projecting from its shell, though in the fossil they are generally broken off; *Inoceramus*, of several species, a ponderous shell, whose fragments are very common; and *Pecten*.

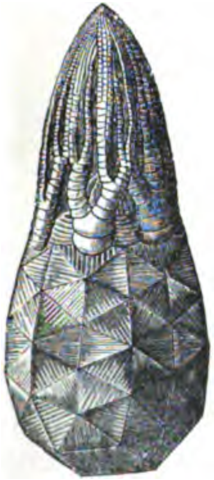
Ammonites occur abundantly in the Chalk-marl, including the species *Rothomagensis*, *Mantelli*, and *varians*, but, after

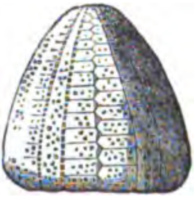


Ananchytes.



Micraster.





Marsupites. *Galerites.*

FIG. 267.—A group of Echinoderms from the chalk.

that, they die out, and are seen no more. In the chalk the ordinary bony fish which predominates at the present day is first met with, the most characteristic being several species of *Beryx*. In addition, sharks and rays abounded, if we are to judge by the number of teeth which are found. The palatal or grinding teeth of *Ptychodus*, a kind of ray, are called "slugs" by the quarry-men, from their resemblance to a slug when contracted. The remains of Ichthyosaurus, Plesiosaurus, and other reptiles are scarce, and with this formation they also come to an end.

The chalk was probably deposited in much deeper water than the sands and clays that preceded it, and the gradually diminishing quantity of clay from the bottom upwards suggests a gradual deepening of the water. Moreover, as has been shown, the Lower Cretaceous beds did not extend over the Palæozoic ridge in the lower Thames basin, whereas the Upper Cretaceous series rests upon it, which shows that it was then sea-bottom. A recent boring at Dover has demonstrated that this Palæozoic ridge, which there consists of coal-measure strata with apparently workable coals, is 1160 feet below high-water mark. The fossils also, and the absence of any sediment, give evidence of water deep enough, or, at any rate, far enough removed from the land, to be clear. The fact that a large proportion of the chalk is composed of foraminiferous shells is evidence of its slow accumulation, as it is not thought likely that they would form a layer on the sea-bottom more than a quarter of an inch thick in a year. At this rate, the deposition of the Norwich chalk, which is more than 1000 feet thick, would have occupied fifty thousand years.

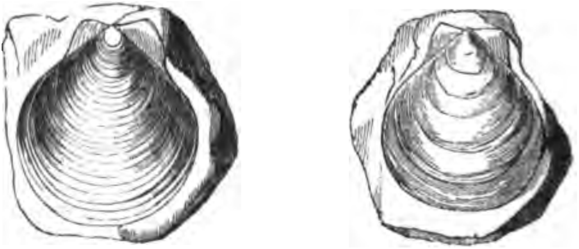


FIG. 268.—*Pecten orbicularis.*

Some years ago, when the bottom of the Atlantic was first surveyed by the *Lightning* and *Porcupine*, it was found that a deposit, which we now know as the globigerina ooze, was forming in the depths of the Atlantic. It was remarked that it bears in some respects a striking resemblance in composition to the chalk, and it suggested the idea that chalk was, like it, a deep-sea deposit, and that probably the globigerina ooze represented the chalk which was not elevated into dry land, and which had been forming ever since. This led to the expression that we were still living in the Chalk period. Chalk, however, is now believed to be a comparatively shallow-water deposit, and we cannot be said to be living in the Chalk period, if practically all the species then living do not now exist, which is the case. All the species of siliceous sponges, echinoderms, shells, and fishes which are found in the chalk are now extinct, and have been succeeded by other forms of life.

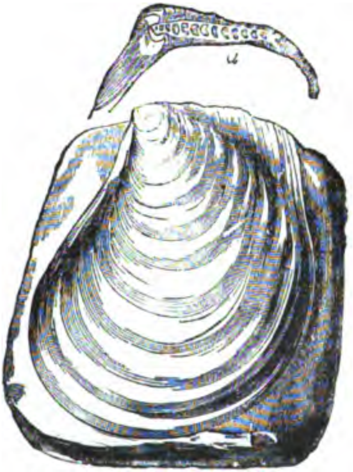


FIG. 269.—*Inoceramus*. *a*, hinge.

In comparing the fossils of the Oolitic and Cretaceous systems, we note that many Oolitic genera do not reappear in the Cretaceous rocks. Among these may be mentioned the lamellibranchs, *Isocardia*, *Cardinia*, and *Posidonomya*; *Clypeus*, an echinoderm; and many subgenera of Ammonites. On the other hand, many new genera arise, some of which, such as *Siphonia*, *Ventriculites*, *Hippurites*, *Baculites*, *Hamites*, *Scaphites*, *Turrilites*, *Belemnitella*, *Galerites*, *Ananchytes*, *Holaster*, *Micraster*—are confined to the Cretaceous system; while other genera, such as *Chama*,

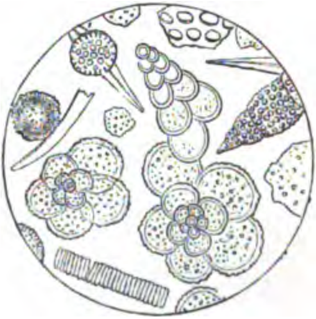


FIG. 270.—Organisms in Atlantic Ooze, chiefly Foraminiferæ, with a few Radiolaria and sponge-spicules (highly magnified).

Petunculus, *Pleurotoma*, *Rostellaria*, *Melanopsis*, and other gasteropods, come in with the Cretaceous period, and survive to the present day. These changes indicate considerable lapse of time, during a part of which, in the south of England, the fresh-water series was being deposited; while on the Continent the marine Neocomian beds, where the transition is much more gradual, were formed.

The Upper Cretaceous areas of the northern part of Europe, that is, of the north of France, Belgium, Denmark, and Russia, more or less resemble the English, white chalk being the characteristic formation. In the Chalk epoch, the Ardennes formed a shore-line, and in this region sedimentary deposits were formed on the uneven floor of older rocks. These deposits are often pebbly at the bottom; and near Aix-la-Chapelle there is a series of beds of the age of the Chalk-with-flints, lying in a hollow, and containing a very abundant flora, no doubt brought down by streams from the Ardennes. In this flora we have the first appearance of the highest division of the vegetable kingdom, viz., the "angiosperms," which comprises all the ordinary flowering trees and plants. In the Lower Cretaceous beds these are not found, the highest plants

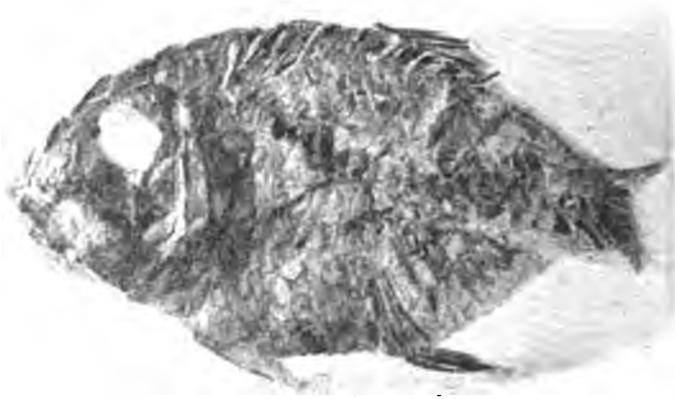


FIG. 271.—*Beryx*. Chalk. (Jermyn Street Museum.

being "gymnosperms," such as cycads and conifers, analogous to those of the Jurassic system, together with various cryptogams. But here the prevailing forms belong to the highest type, and are found in very great abundance and variety, including species of oak, fig, walnut, and many genera of proteaceæ, including Banksia, etc. It is evident that these higher plants must have been flourishing on the earth for a long period antecedent to the Chalk, so that it is not at all unlikely that remains of some of them may at some time be discovered in much older strata. Near Mons the upper beds of the Chalk are rich in phosphate of lime, which has probably owed its origin originally to the presence of large quantities of decomposing fish-remains.

At Maestricht, in Holland, there is a soft yellowish coralline limestone lying unconformably upon the Chalk, which contains an interesting admixture of Cretaceous and Tertiary fossils—Cretaceous *Belemnitella*, *Baculites*, *Ananchytes*, *Inoceramus*, and others being associated with such Tertiary and recent genera of gasteropods as *Voluta*, *Oliva*, and *Mitra*. At Faxoe, in the south of the Danish island of Zeeland, there is a similar case. These Maestricht and Faxoe beds are evidently more recent than any Cretaceous strata we have in England, and may be regarded as "passage beds" leading from the Cretaceous to the Tertiary system.

In Saxony and Bohemia the Upper Cretaceous beds rest unconformably upon older rocks, and consist mainly of hard sandstones, with numerous angiosperms, palms, and other plants suggestive of a warm climate, in their lower beds.

Throughout the south of Europe the most characteristic formation of the Upper Cretaceous is the *hippurite limestone*, so called from the presence in it of great numbers of various species of *hippurites*—a curious elongated bivalve with one shell somewhat like a horn, and the other much smaller, serving as a lid. There are several species, and the genus is confined to the Cretaceous system. This hippurite limestone ranges through the Levant and Palestine to Persia, and is also found in North Africa.

In Central India there are fresh-water strata of Upper Cretaceous age, with contemporary basalts interbedded; while in the south there are marine beds with fossils of the same genera, such as *Ammonites*, *Turrilites*, *Exogyra*, etc., and many of the same species as the European beds. The Cretaceous system also occurs in Queensland and in New Zealand. In the latter region it contains coals and fossils of European genera, but not identical in species. The fossil flora of some of the New Zealand strata includes angiosperms and conifers not unlike the native plants of the present day, mingled with ferns and others characteristic of the Jurassic period.

Cretaceous rocks occur in North America, both on the Atlantic and Pacific seaboards, as well as in the Mississippi valley. The most notable fact in connection with these beds is the number of enormous reptiles and of wading and diving birds which some of them have yielded; one of the latter, named the *Hesperornis*, being five feet high. There is also a large and wide-spread lignite and coal-bearing series, containing the same kind of admixture of Tertiary and Cretaceous fossils as characterizes the Maestricht and Faxoe beds. The flora has a distinctly Tertiary aspect, and comprises species of fig, magnolia, oak, and many others; while the fauna is Cretaceous, and consists of European species of *Belemnites*, *Inoceramus*, *Ostrea*, *Nautilus*, etc. These may probably be most conveniently regarded as transition beds.

SUMMARY.—The Cretaceous system as developed in England consists of a series of sands and clays, some fresh-water, below, and a thick bed of white chalk above. Much of it lies in the London and Hampshire basins; its western boundary, like that of the Jurassic rocks, stretches across the country from Dorsetshire to Yorkshire, while to the east the system sinks below the Tertiary beds. There is a considerable break between the chalk and the overlying Tertiaries, but this is to some extent bridged over by certain continental beds.

QUESTIONS.

1. Describe the position of the Cretaceous rocks in the south of England, and illustrate it with a geological section.
2. Contrast the Lower Cretaceous rocks with those of Switzerland.
3. Describe fully the physical geology of the North Downs, especially in relation to water-supply.
4. What is the chemical composition of the chalk? and what is the nature of the soil which is left after its denudation?

THE CRETACEOUS SYSTEM.

Scale: 1 inch = 500 feet; about 2,250 feet.

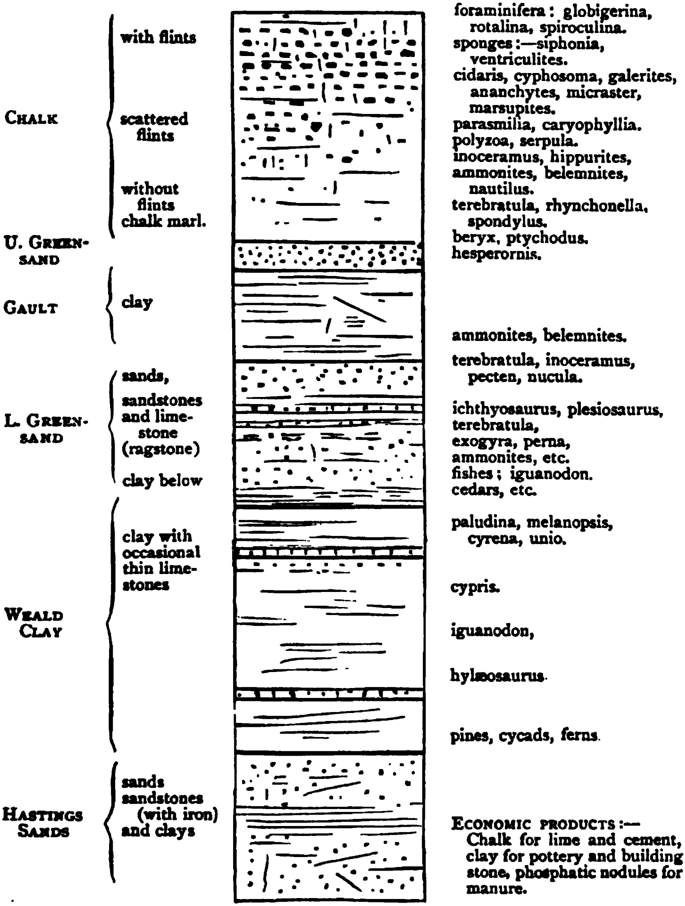

CHALK
with flints
scattered flints
without flints
chalk marl.
U. GREEN-SAND
GAULT
clay
L. GREEN-SAND
sands,
sandstones and lime-stone (ragstone)
clay below
WEALD CLAY
clay with occasional thin lime-stones
HASTINGS SANDS
sands
sandstones (with iron)
and clays
foraminifera: globigerina, rotalina, spiroculina.
sponges:—siphonia, ventriculites.
cidaris, cyphosoma, galerites, ananchytes, micraster, marsupites.
parasmilia, caryophyllia.
polyzoa, serpula.
inoceramus, hippurites,
ammonites, belemnites, nautilus.
terebratula, rhynchonella, spondylus.
beryx, ptychodus.
hesperornis.
ammonites, belemnites.
terebratula, inoceramus, pecten, nucula.
ichthyosaurus, plesiosaurus,
terebratula,
exogyra, perna,
ammonites, etc.
fishes; iguanodon.
cedars, etc.
paludina, melanopsis, cyrena, unio.
cypris.
iguanodon,
hylæosaurus.
pines, cycads, ferns.
ECONOMIC PRODUCTS:—
Chalk for lime and cement, clay for pottery and building stone, phosphatic nodules for manure.

FIG. 272.

5. What is flint? How has it probably been formed?

6. Discuss the question as to the conditions under which the chalk was formed.

7. Compare the fossils of the Cretaceous system with those of the preceding and succeeding systems.

8. What continental Cretaceous deposits are of later date than the English chalk? Describe them and their fossils.

9. Give an account of the North American Cretaceous rocks.

10. Classify the following fossils, and say in what Cretaceous formation they may be found:—*Spondylus*, *Baculites*, *Exogyra*, *Iguanodon*, *Inoceramus*, *Ventriculites*, *Siphonia*, *Cidaris*, *Hippurites*.

CHAPTER XXVIII.

THE CAINOZOIC GROUP.

THE Mesozoic era ended with the Cretaceous period, and the last relic of it in England, so far as is known, is the chalk, although, as has been shown, there are more recent beds preserved in European localities. The Cretaceous period closed with a general uplifting of the sea-bottom throughout the European area. The recently deposited Chalk strata were for the most part converted into dry land, in some parts greatly bent and uptilted in the process, and then apparently subjected to a prolonged period of denudation. It was no doubt at this time that the great Wealden anticlinal was slowly lifted up, converted into a plane of marine denudation, and subsequently further denuded by atmospheric action. Finally, a fresh submergence of the irregular and denuded surface occurred, and new sedimentary deposits of various kinds were thrown down upon it. These new strata, brought from various directions by rivers, or derived from the waste of the shore, vary considerably in character, and are not always easy to correlate, but they agree in lying unconformably on the chalk, and in having practically no species of fossils identically the same as those of the preceding period. This latter fact is very striking, when the great numbers of fossils from the Cretaceous and Tertiary systems are considered, the Cretaceous strata having yielded 2270 species, and the Tertiary 4270; and, whatever may be the reason, it bears witness to a very great lapse of time, inasmuch as between the time of the deposition of the uppermost beds of the chalk, and of the lowest beds of the new system, all the old forms of life either died off, migrated to some fresh but at present unknown locality, or, in the course of natural selection under the influence of changed conditions of life, became modified into the new species which we meet with in the Tertiary system. Very probably each of these three had its share in bringing about the change, combined with the immigration of new forms from neighbouring areas.

These new strata, and all subsequent to them, belong to the Cainozoic division, and with them we enter into what may be considered the modern geological era. Even in the oldest of them there are fossils belonging to species which are still living, and as we ascend in the series, these increase in number until we come to quite recent beds, which contain no extinct forms at all. The names of the divisions of the group have reference to this gradually increasing number of modern forms of life, though from the etymological point of view they are somewhat open to objection. The lowest is called the *Eocene* (*eos*, dawn; *kainos*, recent), the dawn of recent or existing life; next is the *Oligocene* (*oligos*, few), containing only few living forms; next the *Miocene* (*meion*, less), containing more than the preceding, though less than the *Pliocene* (*pleion*, more), and the highest is the *Pleistocene* (*pleistos*, most), which contains the most existing species. The term *Tertiary* has been employed to denote all these formations, but it has become usual to confine it to the first four, and to call the last Post-Tertiary. The Cainozoic group therefore stands as follows:—

Post-Tertiary system: *Pleistocene*, also called *Quaternary*.
Tertiary system: (4) *Pliocene*.
(3) *Miocene*.
(2) *Oligocene*.
(1) *Eocene*.

The Lower Eocene strata were deposited mainly on the denuded surface of the chalk. The lowest beds lie in the deepest depressions, these being the parts which were first submerged. They are consequently not quite contemporaneous, and are isolated from each other. There are four well-defined hollows in which these beds lie, namely the London and Hampshire basins, which have been already mentioned, and the continental basins of Paris and Belgium. The last contains the oldest Tertiary strata, viz. those of Mons, which consist of a variety of clayey, sandy, and calcareous deposits, containing fossils mainly, but not quite exclusively, marine. A peculiarity of these fossils is that they bear a much greater resemblance to the fossils of certain beds in the Paris basin which belong to a much later time, than they do to those of the beds which immediately succeed them. It looks as if some geographical change drove away many of the creatures which flourished at this time in the Mons area, and that they afterwards returned when conditions again became favourable. It is quite certain that the Upper Eocene Paris beds belong to a much later epoch than those of Mons, so that it is evident that similarity of fossils is not an absolute proof of contemporaneity of deposition, especially when the two sets of strata are some distance apart.

In Belgium the Mons beds are succeeded by the Landenian, these being the equivalents of the Thanet sands and Woolwich and Reading beds of the English basins.

The **Thanet sands** are the lowest of the English Tertiaries, and are so named because they are well displayed in a cliff at Pegwell, in the Isle of Thanet. They rest unconformably upon the chalk, and contain at their base a layer of dark green-coloured unworn flints, the insoluble residue of the denuded chalk, the green colour being a superficial coating of silicate of iron due to the action of ferruginous water upon the flint. They can hardly be considered as belonging to the Thanet sands, as they occur under more recent strata when these strata rest directly on the chalk. Fossils are fairly abundant in the sands, which occur not only in Thanet, but at various points at the foot of the northern slope of the North Downs. These Thanet sands are unrepresented both in the Hampshire and Paris basins, but in Belgium they are represented by the Lower Landenian strata, in the lower portion of which is found a collection of plant remains, such as oak, chestnut, willow, etc., suggestive of temperate conditions.

The **Woolwich and Reading beds** consist of a series of clays, thick and thin, and sands. They are wide-spread but variable. For instance, in the Hampshire basin clay predominates, in the London basin sand, with false bedding and rolled pebbles, evidently derived from a not far-distant beach. In some places hard irregular sandstones are found in these beds; and blocks of these stones lying directly on the chalk which spreads round the London basin bear witness to the fact that the

Tertiary strata once extended much further than they do at present. These stones are very common on the chalk downs, where they are called *grey wethers*. In olden times they were largely used for stone circles, cromlechs, and other monuments, and have been in more recent times applied to building purposes. The lowest or basement bed is a pebbly sand, and contains a large species of oyster, *Ostrea bellovacina*, with sharks' teeth and crustaceans, and in the Reading district in the same horizon, beautifully preserved in a laminated clay, plant-remains are found which agree in general character with those found in Belgium. Near Woolwich, estuarine fossils, such as *Melania*, *Melanopsis*, etc., are found in the lower beds, and even fresh-water shells, such as *Paludina;* and marine shells, and fish-teeth in the upper. At the top of the series is a wide-spread layer of small water-worn flint pebbles, which varies from an inch to thirty feet in thickness, sometimes lying loose, with the interspaces filled up with sand, and sometimes connected together into a hard conglomerate. It is known as the **Oldhaven bed**, and may be seen in the cliff between Herne Bay and Reculvers on the north coast of Kent, in the railway cuttings near Bromley, and at various other localities.

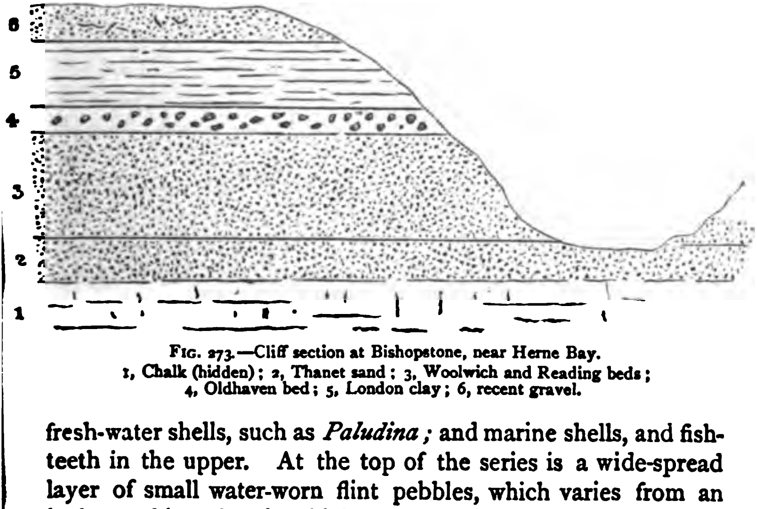


Fig. 273.—Cliff section at Bishopstone, near Herne Bay.
1, Chalk (hidden); 2, Thanet sand; 3, Woolwich and Reading beds; 4, Oldhaven bed; 5, London clay; 6, recent gravel.

The preceding strata all show indications, in the London basin, of having been deposited in the estuary of a great river flowing somewhat in the position of our present Thames. As they are followed from Reading eastward to Thanet the material becomes finer, the plant remains rarer, and marine fossils more abundant. An interesting and very complete section of the marine type of these beds is displayed in the cliff in North Kent. At Reculvers the Thanet sands occupy the greater part of the cliff, and dip gently westward under the Woolwich and Reading beds, which themselves similarly dip under the London clay.

The **London clay** is a bed of tenacious bluish clay, about four hundred feet thick, resting on the Oldhaven pebble bed, when it is present. As its name denotes, it is located in the London basin. It is also found in Hampshire and Belgium. It contains layers of clayey calcareous nodules (*septaria*) used for cement, pyrites, crystals of selenite, and numerous fossils. One of the best localities for viewing it is the north coast of Sheppey. Here the cliffs, crumbled by winter frosts and washed down by the rain, yield numerous pyritized fossils, which are washed about and sorted out by the waves, and left in long lines along the muddy shore. The majority are unrecognizable, though they have evidently consisted originally of some kind of vegetable matter; but now and then there are found perfect and well-preserved specimens of the wood, fruit, and seeds of the palm, screw-pine, cypress, yew, and other familiar trees. They are, however, difficult to preserve, as the pyrites oxidizes and causes the fossils to disintegrate. The wood is often perforated by the tubes of a marine worm, *teredo*. In addition to vegetable remains, crustaceans of the crab and lobster orders are common, together with mollusca, especially lamellibranchs and gasteropods, among the former being species of *Avicula*, *Cyprina*, *Modiola*, and *Pholadomya;* and among the latter, species of *Fusus*, *Conus*,

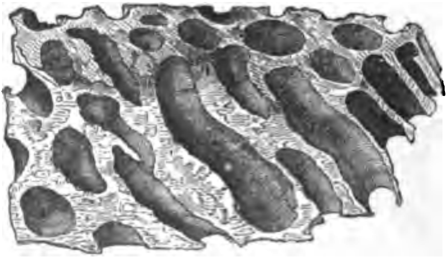


FIG. 274.—Wood perforated by the *teredo*, from the London clay.

Pleurotoma, *Rostellaria*, etc. Fish-remains, especially sharks' teeth and bones of members of the highest division of fishes, the bony or Teleostean, are very numerous. A curious web-footed toothed bird, the *Odontopteryx*, a vulture, kingfisher, crocodiles, snakes, and turtles are also represented, a series of remains suggestive of the estuary of an African rather than an English river, and bearing witness to a climate and other geographical conditions very different to the present.

In Belgium and north-east France the English Lower Eocene is represented by the Landenian and Ypresian systems, the upper and lower divisions of the former corresponding respectively to the Thanet sands and the Woolwich and Reading beds, and the latter to the London clay. In the Paris basin the Thanet sands are probably not represented. The Woolwich and Reading beds are represented by marine sands (*sables de Bracheux*), possessing many fossils in common with their marine equivalents in England, by lignitiferous beds, calcareous tufa with plant remains, and other fresh-water deposits, and by beds of clay known as *argile plastique*, largely used for pottery.

Above the London clay, in the London basin, are the **Bagshot sands**, containing a few marine fossils, chiefly in clays and greensands in the central portion of the series. The area occupied by these sands is, for the most part, sterile though picturesque, and constitues the heather and pine-clad country which occupies the north-east corner of Hampshire and the adjoining parts of Berkshire and Surrey. The equivalents of these sands in the Hampshire basin are the Bracklesham and probably the Barton series. The former are well displayed on the Hampshire coast and near the east and west extremities of the Isle of Wight. At Alum Bay, the western locality, the sands are nearly vertical, and display bands of every colour, but are unfossiliferous. In other localities on the Hampshire coast, near Bournemouth, near Selsea Bill, and at Whitecliff Bay in the Isle of Wight, they are more or less fossiliferous. Between Poole and Bournemouth a few thin beds have yielded an abundant and varied series of plant remains; while at Selsea Bill large numbers of molluscous shells are found. Species of *Cerithium* and *Turritella* are characteristic among gasteropods, and of *Cardita* among bivalves. The Barton clay, which is well seen in the cliffs between the mouth of the Avon and Hurst Castle, has yielded a profusion of extremely well-preserved fossils, especially gasteropods, such as *Pleurotoma*, *Fusus*, *Voluta*, *Oliva*.

At Bovey Tracey, in Devonshire, there is a lacustrine deposit consisting of grits and kaolin derived from the Dartmoor granite, containing a considerable assortment of plant remains, including fig, oak, laurel, water-lily, and various fruits and cones. Beds of lignite are also abundant, and have been worked for local use as fuel for nearly two hundred years. Some forty years ago Professor Heer, a Swiss geologist, examined the plant remains, and concluded that they were contemporaneous with the Swiss Miocene series; but more recent and extensive investigations by Mr. J. Starkie Gardner, and a careful comparison with his collection from the Bournemouth beds, have led Mr. Gardner to conclude that they are of the same age as the latter. In the Isle of Mull and in

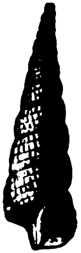


Fig. 275.—*Cerithium*.

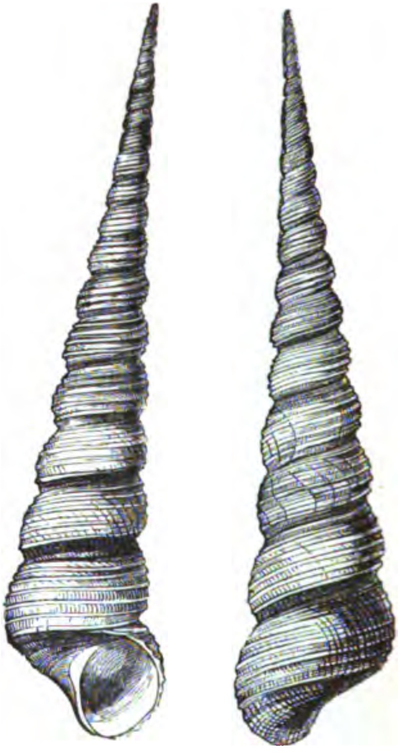


Fig. 276.—*Turritella*.

Antrim very similar sets of remains have been found in thin beds which lie among the great sheets of basalt which stretch around and between those two localities, and these, no doubt, also belong to the Bagshot age, and not to the Miocene, as was formerly supposed. The basaltic sheets bear witness to a very great Tertiary volcanic outburst, which covered hundreds of square miles with lava, and no doubt these leaf beds represent the old soil which formed in course of time on the decaying surface of the lava, and which were successively buried by renewed eruptions. The remarkable basaltic columns of Staffa and of the Giant's-Causeway belong to this age.

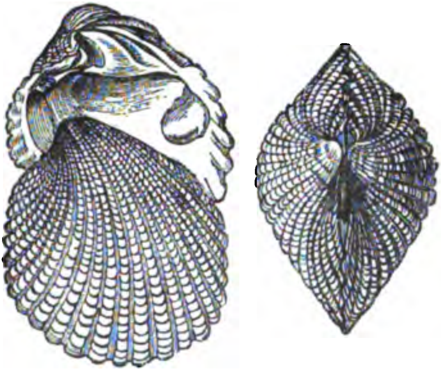


FIG. 277.—*Cardita.*

While the Bagshot and Bracklesham beds were being formed in the north, a great ocean, several times as large as the present Mediterranean, extended over the southern half of Europe and the north of Africa and far into Asia. In this area foraminifera, especially of the genus *Nummulites*, thrived exceedingly, and their remains formed an enormous accumulation at the bottom, in some parts thousands of feet thick. This is now the **Nummulitic limestone** which stretches through Southern Europe, North Africa, and Egypt, through

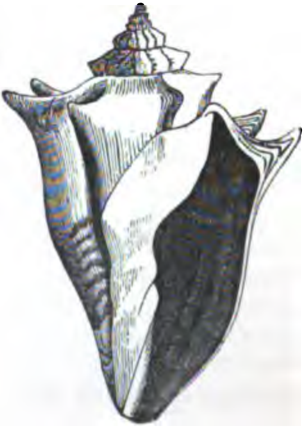


FIG. 278.—*Voluta Solandri* (Barton).

Persia and India to China. This limestone is by far the largest and most remarkable of all the Tertiary strata. It enters largely into the composition of the loftiest portions of the great mountain ranges of the Alps, Pyrenees, Carpathians, and Himalayas—a fact which proves to us that these mountains, which are at present such marked features of the globe, and which have such an important influence on the drainage systems, climate, and productions of the Old World, are really of geologically recent origin. The nummulites are flat circular shells (*nummus*, a coin), and, though more than fifty species occur in the limestone, they are almost confined to this particular formation, none apparently descending so low as the London clay, and only one or two ascending into the Miocene.

After its deposition, the Nummulitic limestone of the Alps was upheaved some thousands of feet, and Miocene strata deposited around it. The presence of the Œningen lake tells us that the salt water had been shut off by the upheaval. But broken, bent, and uplifted Miocene strata bear witness to a subsequent elevation; and, still later, strata of Pliocene age in the same condition testify to still another disturbance. It is therefore clear that the present Alpine system is due to a long-continued succession of disturbances, extending from Eocene to Pliocene times.

The volcanic outbursts of the north appear to have been a local development of a general disturbance and upheaval of much of the Eocene area, which, in the west of Europe, by elevation in one part and subsidence in another, resulted in the formation of a region of lakes, lagoons, deltas, marine areas, and dry land. These **Oligocene** deposits therefore vary much with the locality. In England they are mainly freshwater, and are only found in the Hampshire basin. The best general view of them may be obtained at Alum Bay, near the Needles. The series consists of four divisions, named after localities in the Isle of Wight, where they are well displayed, viz. :—

(4) Hempstead beds.
(3) Bembridge beds.
(2) Osborne beds.
(1) Headon beds.

They consist of marls, clays, sand, and a few beds of limestone, and they succeed one another with perfect uniformity. Some contain exclusively fresh-water shells, such as *Unio*, *Limnæa*, *Planorbis*, and *Paludina;* and land shells, such as *Helix* and *Bulimus:* others contain only marine shells, such as *Ostrea* of various species, *Cardita planicosta*, *Nucula*, and *Cerithium giganteum:* while others contain an admixture of both. The whole series is highly suggestive of conditions alternating between fresh and salt water, with the former predominating. The limestones are of fresh-water origin, and consist largely of shells; some are very soft and clayey; others, notably one twenty feet thick in the Bembridge beds, are hard and suitable for building. Besides shells, plant-remains occur, and teeth and bones of peculiar animals, such as the *Palæotherium*, a kind of large tapir; the *Anoplotherium*, a bird, *Macrornis;* and a crocodile.

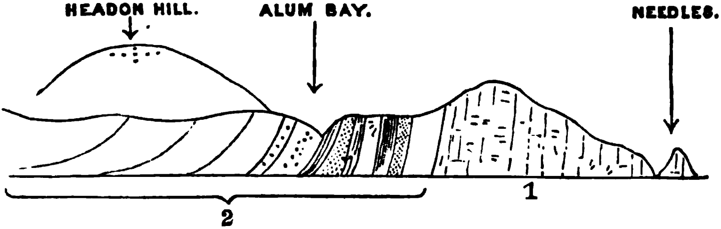


FIG. 279.—1, Chalk; 2, Eocene and Oligocene at Alum Bay and Headon Hill, Isle of Wight.

The Oligocene of the continent of Europe is more distinctly marked. In Belgium it overlaps the Eocene unconformably, and extends over the chalk, and contains a much larger proportion of marine sands and clays, containing species of *Ostrea*, *Cytherea*, *Cerithium*, *Voluta*, *Nucula*, *Cardita*, etc., while here and there occur beds with the usual brackish and fresh-water shells.

In the Paris basin the Oligocene series is very extensive and noteworthy. At its base are marine sands and marls, followed by green and white fresh-water marls, with lenticular deposits of gypsum, largely worked at Montmartre for plaster of Paris. From the marls, Cuvier obtained various extinct mammals. Other important beds follow; marls with hard cellular silicious concretions, largely used for millstones; the *Fontainebleau sandstone* with its curious crystallization; and the *calcaire de Beauce*, a fresh-water deposit with subordinate marine beds. There are other Oligocene areas in Brittany, where the beds rest on a Palæozoic floor; near and east of Bordeaux, where, on the Oolitic plateau, there are deposits apparently of this age, with an enormous quantity of mammalian, reptilian, and bird remains; in Provence, where with mammalian fossils there are associated plant-remains suggestive of Africa rather than Europe; and in Central France, where the upper strata have intercalated beds of volcanic *débris* derived from contemporaneous eruptions of the Auvergne volcanoes. In Switzerland, resting on the Nummulitic series of the Upper Eocene, is an enormous thickness of sandstones and clayey limestones, etc., known as *Flysch*, followed by sandstones and marls (*Molasse*) and coarse conglomerate.

There are large and important Oligocene areas in Germany and Austria. In the lower part, light-coloured estuarine sands and clays alternate, and are associated with numerous beds of lignite, some attaining the remarkable thickness of one hundred feet and more. In the clays are abundant remains of a warm-temperate fauna. Above these is a series, mainly marine, from one of the beds of which most of the Baltic amber is derived. This substance is a fossil resin exuded from various species of pine, and is still more interesting geologically, because it has yielded hundreds of species of insects in a beautiful state of preservation. More sands and clays follow, many of them rich in marine mollusca, with intercalated lignites and abundant traces of a flora belonging to a much warmer region than Germany is at present.

If the recent identification of the beds of Bovey Tracey and Mull as Eocene is correct, there are no known strata of **Miocene** age in the British Isles. They, however, attain considerable stratigraphical and palæontological importance in several continental localities. Fresh-water and estuarine deposits predominate, and in certain localities very extensive and important remains of plants and of gigantic extinct mammals have been found.

In France, Miocene strata extend in all directions round Orleans, and round Agen on the Garonne. They consist of sands, clays, and fresh-water limestones. But the most interesting beds are the shelly sands known as the **Fahluns**, from which upwards of six hundred species of mollusca have been obtained, nearly one quarter of which are still living, many of them in more southern localities, but none in more northern. The most noteworthy and abundant are species of *Cardita*, *Pecten*, *Corbula*, *Cypræa*, *Cerithium*, *Conus*, *Voluta*.

In the fahluns and the associated beds are also found the remains of gigantic extinct land mammals, such as the *Mastodon*, *Dinotherium*, and other pachydermata, ruminant, carnivorous, ungulate, and insect-eating animals, together with birds, snakes, and amphibians. In central France, strata of the same age, with similar fossils, rest upon, and are covered with, masses of basalt from the old volcanoes of Auvergne.

In Switzerland the Lower Miocene consists of lacustrine, estuarine, and marine strata, and the Upper of fresh-water sandstones, marls, and limestones finely laminated, and containing, at Œningen on Lake Constance, a wonderfully varied and well-preserved assortment of fossils, both vegetable and animal. The former, though still bearing witness to a warmer climate than the present, have not so tropical an aspect as those of the Oligocene; palms and evergreens being rarer, and deciduous trees, such as oak, ash, poplar, birch, and alder, more abundant. Ferns, rushes, grasses, and climbing plants also occur. Of insects no less than 826 species, 543 being beetles, have been identified, together with spiders, crustaceans, fishes, reptiles, birds, and mammals. The insects are so perfect that their minute hairs and wing colours have been preserved. Both fauna and flora present examples of species and genera thriving together which are now widely separated. For instance, two crabs are found, one still common in Europe and one not. A salamander occurs, but no salamanders live in Europe at present. A large frog, tortoises, and crocodiles present similar instances. Extinct elephants, rhinoceroses, deer, and ruminants, also abound. Professor Heer, who has carefully studied these beds and their fossils, considers that the climate of the period must have been about 16° Fahr. above what it is at present, *i.e.* that Switzerland had at that time the climate of Sicily. At the same time there is evidence that the temperature was somewhat lower than during the preceding epoch.

At Pikermi in the Morea a remarkably mixed mammalian fauna had been discovered in fresh-water beds, which are probably of Miocene age, a fauna which could never have been supported in Greece with its present geographical limits, but which bears witness to wide-spreading plains and forests in more direct communication with eastern Asia. In addition to the *Mastodon*, *Dinotherium*, and other beasts, there is the *Hipparion*, which was probably the ancestor of the horse; the *Helladotherium*, something between a giraffe and an antelope, the rhinoceros, wild boar, and monkey. A somewhat analogous assemblage is also found in the Siwalik Hills in the Himalayas, near the upper course of the Sutlej; and, among them, a gigantic tortoise, which is estimated to have been about twenty feet long and seven high.

Again, in a locality as distant as California, the same curious mixture of ancient and modern types and of characters now found in different classes is apparent.

Miocene beds also occur near Mayence and along the Danube in Germany and Austria. In the former locality they consist of sands both fresh-water and marine, marls, and fresh-water limestones, and have yielded the usual Miocene mammals and a large assortment of land-shells, including twenty-four species of *Helix*. Near Vienna, fluvio-marine beds with *Mastodon* and *Dinotherium* are succeeded upwards, first by marine sands with abundant fossils of a Mediterranean or southern type, and above them fresh-water strata with fossils suggestive of a colder climate. South of the Alps in Italy, Miocene marls, sandstones, and conglomerates form a vast succession, attaining a thickness of upwards of ten thousand feet.

Still more striking is the fact that on the west coast of Greenland, in 70° N. lat., where now only stunted and hardy Arctic plants can maintain a footing, there are plant-bearing strata containing species of *Sequoia*, *Taxodium*, and other genera, indicative of a climate at least 30° Fahr. warmer; and even in Grinnel land, within 8½° of the North Pole, there are thick beds of lignite with conifers and other Miocene plants. In Spitzbergen also, in 76–79° N. lat., fossil remains of the alder, hazel, and poplar are found. All these facts confirm the conclusion deduced from the European Miocene fossils, that the whole northern hemisphere at this epoch enjoyed a climate much warmer than at present, and, further, that the difference was much more marked in the Arctic than in the Temperate zone.

The absence of Miocene strata from the British areas indicates that during that epoch it was dry land; and the presence of large mammals similar to those of the Continent, both before and immediately after Miocene times, is suggestive of a connection with the Continent. The huge size and numbers and great variety of the mammals found in the Miocene strata of France and Central Europe make it certain that there was away to the northward of that region a great continental area capable of supporting them, and from whence their remains, together with vegetable matter from the forests, were carried by streams into the lakes and estuaries to the southward. From these facts, and those just mentioned in connection with the Alps, it is clear that, although we are now approaching the end of the geological record, the geography of Western Europe was still very different from what it is at present, both in contour, drainage, and climate.

At the close of the Miocene epoch the British area again sunk below the sea to such an extent that the North Downs, which are now in places more than six hundred feet above the sea-level, were submerged. This conclusion is derived entirely from fossil evidence. Along the ridge of the North Downs, and on the chalk plateau behind them, the surface of the chalk is very uneven and full of "pipes," or deep irregular cavities, evidently due to the solvent action of water acting downwards along joints and fractures. These pipes are now filled up, in some cases with sand, in others with clay, and often with both. The sand is probably, in many cases, the last remnants of Lower Eocene beds, which once extended over the top of the chalk, but have since been largely removed by denudation. On the Downs above

Lenham, between Ashford and Maidstone, however, some of the pipe sands have been found to contain fossils, such as species of *Petunculus*, *Panopæa*, etc., which stamp them as belonging, not to the Lower Eocene, but to the Pliocene. This, like the case of the Bovey Tracey beds, is an instance of the application of palæontological evidence in determining the geological horizon of a deposit when stratigraphical evidence is not forthcoming. These sands rest on the chalk, and have no other strata resting upon them. They may therefore belong to any period subsequent to that of the chalk, and a study of their mineral character throws no further light on the question. The fossils, however, in the hands of Mr. Clement Reid, have given a definite answer where other methods fail. A somewhat similar deposit lies on the Devonian states at St. Erth, near Penzance, and has, from the same kind of evidence, been recognized as Pliocene.

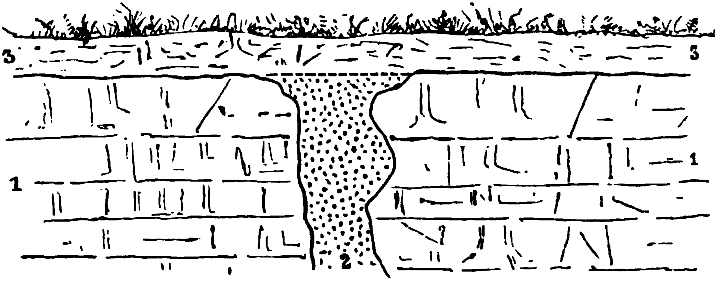


FIG. 280.—Pipe in the chalk filled with sand.
1, chalk; 2, Tertiaries; and 3, soil.

The main mass of the Pliocene in England, however, consists of the shelly sands and gravels known as the **Crag**, which cover a considerable portion of the east of Suffolk and Norfolk. The lowest division is the **White** or **Coralline Crag**, which consists of beds of calcareous sand with great numbers of Polyzoa, or "corallines," still remaining in the position of growth. There are, however, at the base of these beds, nodules and fragments which apparently belong to a still older Pliocene deposit, and which contain remains of mastodons, sharks, etc. The White Crag also yields more than a hundred species of foraminifera; bivalves, including species of *Cyprina*, *Pecten*, *Panopæa;* and gasteropods, such as *Fusus* and *Voluta*. A brachiopod, *Terebratula grandis*, is very common.

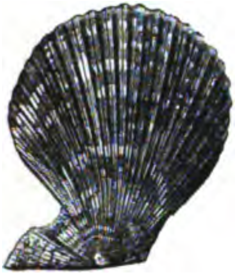


FIG. 281.—*Pecten varius* (crag and still living).

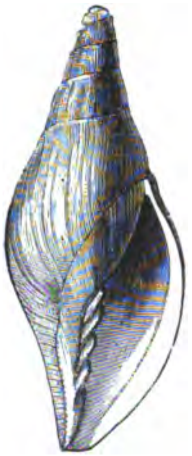


FIG. 282.—*Voluta Lamberti* (white crag).

The **Red Crag** rests unconformably upon the white crag, and is to some extent the result of its denudation, so that White Crag fossils are found mixed with those of the Red Crag age. The beds are coloured red with iron; they contain large numbers of shells, whole and broken; and, like the upper beds of the white crag, are false-bedded, giving evidence of shallow water and tidal action. They extend along the coast between Aldborough and Walton-on-the-Naze, and rest generally on the white crag, but sometimes on the London clay. Phosphatic nodules are found near the base, and are utilized for manure. A well-known gasteropod shell is the *Fusus contrarius* (Fig. 283), a whelk shell which coils the "wrong way." Molluscous shells are abundant, about seventy-five per cent. being common to the white crag, and twenty-five per cent. being new species. Mammalian remains are also found in Coprolite beds of this age, which are largely worked for manure.

When the red crag is followed northward its beds are found to get more scanty, and the fossils suggestive of shallow and more or less fresh-water conditions. Shallow water is denoted by the presence of greater numbers of *Littorina*, *Mactra* (Fig. 284), and other shallow-water molluscs, and fresh water by the appearance of *Paludina* and *Limnæa.* The same character is maintained more or less in the light-coloured sands, laminated clays, and pebbly gravels which succeed them, to which the name of **Norwich Crag** has been given. The bottom bed, called the "Stone bed," consists of large flat pebbles, mixed with bones of mammals, such as *Mastodon*, two species of elephant now extinct, *Elephas meridionalis* and *E. antiquus*, with species, also extinct, of hippopotamus, horse, and many others.

There are two interesting points to observe in connection with these three Crags. The first is the gradual increase of existing species. Taking the mollusca, because they are by far the most abundant class, we find the following percentages of forms now living :—

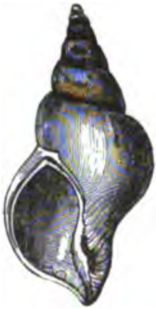


FIG. 283.—*Fusus contrarius.*

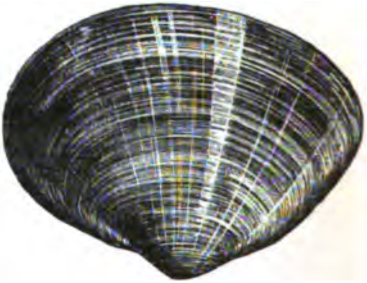


FIG. 284.—*Mactra.*

3. Norwich crag	94
2. Red crag	92
1. White crag	84
[Miocene of Switzerland	31]

The other point is the gradual change which can be seen coming over the climate. We have noticed that in the London clay, Oligocene and Miocene, there is strong evidence of a climate always warm and sometimes tropical. In the London clay, palm-trees, snakes, and turtles mingle their remains with the shells of such tropical gasteropods as *Conus*, *Oliva*, *Voluta;* while, later on, in the Oligocene strata, remains of warm temperate forms of vegetation such as the myrtle abound. In the Pliocene beds we have clear proof of a gradually diminishing temperature. The evidence of this is again most conveniently taken from the marine mollusca. Taking into account, as being safer, living species only, we find that warm water species gradually diminish in numbers, while at the same time, cold water or Arctic species increase. The following table gives the percentage of each division.

	Number of Species still surviving.	Percentage of Species now found in Warm Seas only.	Percentage of Species now found in Arctic Seas only.
3. Norwich Crag ...	130	9	13
2. Red Crag	216	15	10
1. White Crag ...	264	25	5

Among characteristic Arctic shells found in the upper portions of the Pliocene may be mentioned *Scalaria Grœnlandica*, *Astarte borealis*, *Cardium Grœnlandicum*, *Cyprina Islandica*.

The **Chillesford sands** are probably of the same age as the Norwich crag, but the clays which succeed are more recent, and their upper surface appears to have formed the soil in which grew a forest whose remains, in the shape of broken stumps and roots, still *in situ*, may still be seen along the Norfolk coast. This is known as the *Forest bed*, and probably may be considered as the last member of the Pliocene in England. The forest was of a temperate aspect, consisting largely of spruce and other firs, pines, yew, oak, beech, and willow, and with them a large assemblage of water plants such as water-plantain, reeds, pond-weed, water-lily, mares'-tails, etc. With the clays there are associated sandy clays and gravels known as the *Elephant bed*, with remains of elephant, rhinoceros, hippopotamus, horse, bear, beaver, and deer.

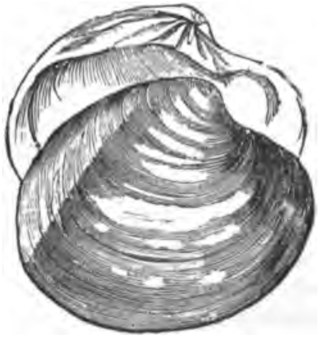


FIG. 285.—*Cyprina Islandica.*

The marine beds of the Pliocene epoch, both in England and on the Continent, are near the present coasts; those far from the sea are lacustrine. They consist for the most part of light-coloured sands and clays with more or less abundant fossils. In Belgium some of the lower beds contain a large assemblage of bones of *cetaceæ;* above them are beds rich in *polyzoa*, which probably correspond with the white crag; followed by other sands, etc., which have been correlated with the red crag. In Holland the Pliocene strata have been proved, by borings in several localities, to reach the unusual thickness of five or six hundred feet. In France there are marine beds in the north, and also on the Mediterranean coast, the latter containing about 35 per cent. of recent species, and probably therefore of much earlier date than our crags. The Auvergne volcanic *débris* of this epoch contains numerous well-preserved fossils. But it is in Italy that the Pliocene strata attain their greatest development, where they are represented by thick beds of sand and clay more than one thousand feet thick, with at Rome a rich assemblage of molluscan remains, and in the Val d'Arno an extensive series of the bones of mammalia. The Roman beds of Monte Mario have yielded three hundred species of mollusca, half of them identical with species found in the English crags. No Pliocene beds have been recognized in Australia, but in New Zealand they occur both as fossiliferous marine beds with ninety per cent. of existing species, and as auriferous gravels. A rich mammalian fauna has also been found in the Pliocene beds of the United States. A general review of the Pliocene series all over the world gives the impression that, at its close, the great masses of land had in a general way taken their existing configuration, and that plant and animal life had to a large extent approximated to its present condition, both as regards species and distribution.

SUMMARY.—The Tertiary or Cainozoic system consists of a varied series of marine and fresh-water beds in which unconsolidated strata predominate. Great geographical changes occurred during the Tertiary epoch, and at its conclusion the outlines and contours of the great land masses had assumed their present form.

THE TERTIARY SYSTEM.

Scale: 1 inch = 400 feet.

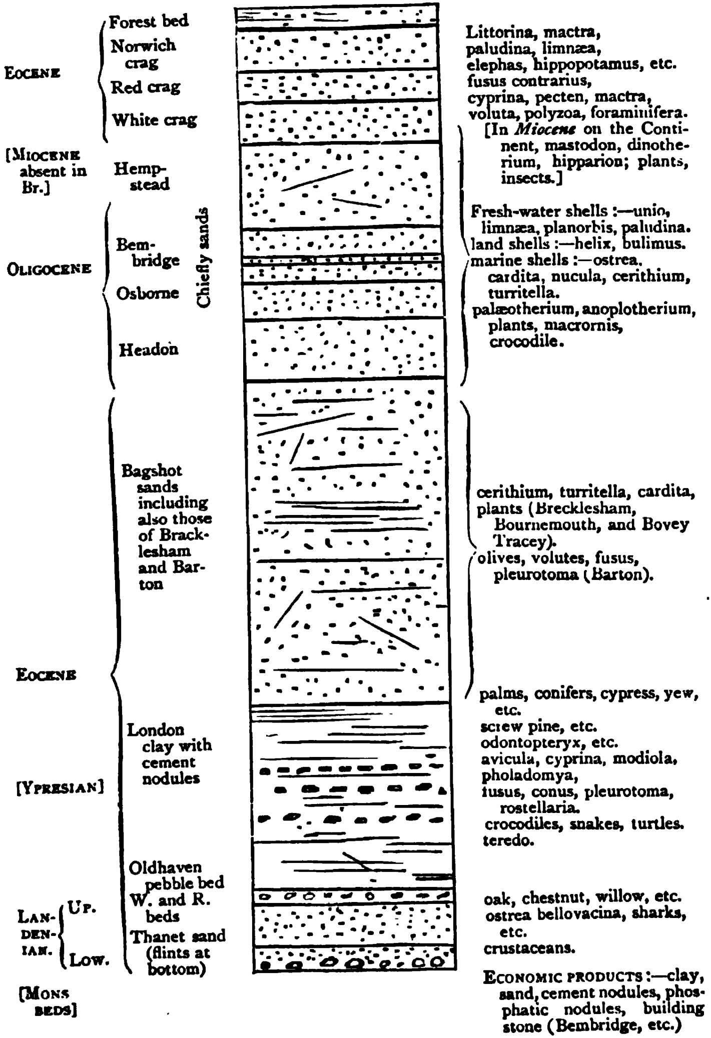

EOCENE
Forest bed
Norwich crag
Red crag
White crag
[MIOCENE absent in Br.]
Hempstead
OLIGOCENE
Bembridge
Osborne
Headon
Chiefly sands
Bagshot sands including also those of Bracklesham and Barton
EOCENE
London clay with cement nodules
[YPRESIAN]
Oldhaven pebble bed
W. and R. beds
LANDENIAN. Up.
Thanet sand (flints at bottom)
Low.
[MONS BEDS]
Littorina, mactra, paludina, limnæa, elephas, hippopotamus, etc.
fusus contrarius, cyprina, pecten, mactra, voluta, polyzoa, foraminifera.
[In *Miocene* on the Continent, mastodon, dinotherium, hipparion; plants, insects.]
Fresh-water shells :—unio, limnæa, planorbis, paludina.
land shells :—helix, bulimus.
marine shells :—ostrea, cardita, nucula, cerithium, turritella.
palæotherium, anoplotherium, plants, macrornis, crocodile.
cerithium, turritella, cardita, plants (Brecklesham, Bournemouth, and Bovey Tracey).
olives, volutes, fusus, pleurotoma (Barton).
palms, conifers, cypress, yew, etc.
screw pine, etc.
odontopteryx, etc.
avicula, cyprina, modiola, pholadomya,
fusus, conus, pleurotoma, rostellaria.
crocodiles, snakes, turtles.
teredo.
oak, chestnut, willow, etc.
ostrea bellovacina, sharks, etc.
crustaceans.
ECONOMIC PRODUCTS :—clay, sand, cement nodules, phosphatic nodules, building stone (Bembridge, etc.)

FIG. 286.

QUESTIONS.

1. Give an account of the geographical changes which occurred in the British area between the deposition of the Chalk and of the Thanet sands, describing the nature of the evidence upon which your conclusions are based.
2. What are the names and characteristics of the divisions of the Cainozoic system.
3. Describe any foreign Cainozoic deposit older than the Thanet sands.
4. Mention any noteworthy strata of (*a*) hard rock, (*b*) clay, (*c*) pebbles in the English Tertiaries.
5. Describe cases of isolated Tertiary beds, the geological position of which has been determined on palæontological evidence.
6. Give an account of the London clay and its fossils, and the conclusions based on them.
7. Recount the geological history of the Alps.
8. Describe any (*a*) English, (*b*) foreign fresh-water Tertiary strata.
9. Explain *grey wethers*, *fahluns*, *flysch*, *molasse*.
10. What is there of special interest in the Pikermi beds?
11. Trace the gradual change of climate in later Tertiary times.
12. Give a list of the chief Tertiary vertebrate fossils.

CHAPTER XXIX.

THE POST-TERTIARY SYSTEM.

THE Norfolk Forest Bed informs us that a considerable portion of the shallow Pliocene sea had become dry land; and we have seen how, during Pliocene times, a gradual change had been coming over the climate, which, from sub-tropical, had passed through warm temperate to temperate conditions. The Forest and Elephant beds are succeeded by a few fluvio-marine clays and sands, known as the **Westleton beds**, from a village near Dunwich, where, and at one or two other localities, they may be seen, and these are followed by the **Glacial deposits**. In the Eastern Counties we have, resting on the crags and succeeding beds, patches of clay containing scratched and ice-worn Jurassic and chalk pebbles, together with pieces of granite, basalt, and other crystalline rocks, which at present are found *in situ* in Scandinavia. These clays pass upwards into sandy clay, sand, and gravel, and then into a mass of chalky rubble, with large chalk boulders and numerous worn fragments of Mesozoic and Palæozoic rocks. Irregular and greatly contorted sands and gravels containing a large quantity of broken shells, apparently derived from the crag, succeed, followed again by boulder-clay, overlaid by flinty gravel. These beds, which are not all found in one section, and are by no means continuous over the area, are suggestive of deposits formed not far from the margin of a glaciated region, where, at one time, the ice intruded and left boulder-clay, at another time moraine *débris*, and at others withdrew altogether, and was replaced for a time by the sea. These clays, with intermediate sands and gravels, can be followed up the east side of England. The clays vary in character according to the formations which lie immediately to the north of them, being chalky in one place, red in another, and carbonaceous in another, and the boulders and smaller stones which they contain all bear witness to a northern origin. Where fossils occur they are either evidently derived from other strata or they are of a northern type.

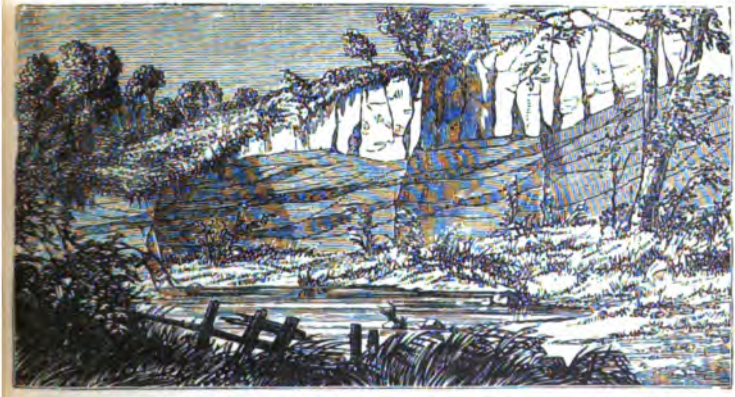


FIG. 287.—Chalky boulder clay (white) resting upon sand and gravel, near Chelmsford.

Down the West of England very similar deposits are found covering the low ground in Stafford, Cheshire, and Lancashire. The lower clay is found on the low ground only, and never rises above five hundred feet, but the intermediate sands rise to high levels. On Moel Tryfan, in North Wales, they are found thirteen hundred feet high, and in Derbyshire eleven hundred feet. The stones in the clay are chiefly derived from

Criffel and other places in the south of Scotland, and from the Lake country; and the lower clay is in many places found to rest on a smoothed and striated rock surface. The difference in level of the lower boulder-clay and the sands shows us that considerable geographical changes occurred at this time.

In Scotland the thick clay, or *till*, covers the lowlands and valleys, and has at its base in some places beds containing Arctic shells, in others plant and mammalian remains, the latter probably the sweepings of the old land surface which was invaded by the ice.

The persistence with which the intermediate sandy beds recur makes it pretty certain that the glacial epoch, after enduring for a time, and apparently covering a large portion of the British Isles with an ice-sheet, gradually gave place to somewhat milder times, when, owing to a general subsidence, the sea covered a large part of the country, and converted it into an archipelago of rocky islands. During this submergence, the intermediate, and now often high-lying, beds of sand and gravel with their Arctic shells were formed. As the land rose, the cold returned, and with it the ice-sheet, and the upper boulder-clay was formed. When the cold was most intense it seems probable that all the country north of the Thames and Bristol Channel was deeply covered, though, probably, not quite to such an extent as Greenland is at present; for although the glacial striæ, boulders, and erratic blocks show that the smaller valleys and minor inequalities were disregarded, yet nevertheless there is evidence that the Highlands of Scotland, the Lake District, and North Wales, and, in a minor degree, smaller hill districts, such as Charnwood, acted as centres from which the ice pressed outwards in all directions, though the various streams from these different points came into contact and influenced each other. Thus a very large flow extended southward from Scotland, passing over the Irish Sea, pressing against and diverting southward another stream from the Lake Country, and interfering with the system of North Wales. These conclusions are drawn from such facts as the direction of glacial striæ where there are any, and more particularly from the distribution of boulders and glaciated stones

For example, glacial scratches run north and south across the Isle of Man, and easily recognized boulders from the south of Scotland are found in North Wales, and, mingled with Lake country stones, are disseminated through the boulder-clay of Lancashire. From similar evidence we know that an ice-sheet descended from the Scotch Highlands into the North Sea, and was diverted southward and pushed over what is now the east of England by a great Scandinavian ice-sheet. Similarly Charnwood rocks are found in the boulder-clay of Central England. When the Ice age was most intense, the glaciers, at any rate in the higher valleys, were quite obliterated by the all-prevailing sheet of snow and ice, but, as the climate mitigated, the lowlands gradually emerged from their icy mantle, the snow-field became less and less, and was confined to the higher ground, and then the valleys, which before had been filled with and obliterated by the ice, had their bottoms occupied by glaciers. The marks of these later glaciers are still plainly to be seen in Wales and Scotland, notably in the Vale of Llanberis in the former country, and in Glencoe in the latter. As, under the influence of the increasing temperature, the glaciers gradually diminished and retreated up into the hills, they left their terminal and lateral moraines forming confused heaps, and long irregular ridges, at various points in the valleys. Sometimes similar gravels straggle in long mounds across the lowlands, or are scattered about in widespreading heaps, associated with what seems to be rearranged glacial clay, and occasionally, as in Sweden, with enormous numbers of Arctic shells. These latter deposits are known as *eskers* in Ireland, *kaims* in Scotland, and *ösar* in Sweden. They are, no doubt, the result of the action of water, to some extent derived from the melting ice, upon the *débris* left by the retreating ice-sheet. Both the eskers and the valley moraines frequently give rise to lakes, either by pounding back the water or by holding it in hollows on their surface.

There is clear evidence that these glacial conditions existed in a very intense form over Scandinavia and Finland, and that the great ice-sheet pushed its southern limits across the Baltic Sea into Prussia and Russia. At the same time, the cold caused a great extension of the limits of the Alpine and other snow-fields, those of the Alps extending from the mountains down into the lowlands in all directions, carrying, for instance, Alpine boulders across to the eastern slopes of the Jura in one direction, and into Bavaria in the other. The same thing has happened with the Caucasus, the Himalayas, and even with the Atlas in North Africa.

North America shows signs of having been glaciated on its eastern side as far south as the latitude of New York, apparently by ice extending from Greenland. The ice-sheet here must have been of enormous thickness, for glaciated surfaces and perched blocks are found in the Northern Alleghanies at a height of five thousand feet above the sea-level.

The Southern Hemisphere contains much less land in its temperate regions, and this land does not extend towards the Pole like that of the north; but Darwin and other travellers describe evidences of glacial action on the plains fringing the Andes of Chili and Patagonia. The New Zealand glaciers were once much more extensive than at present, and there are glacial clays with scratched stones in South Africa.

It is evident, therefore, that both hemispheres have been glaciated in recent geological times, though, from existing geological evidence, it is apparently quite impossible to tell whether the glaciation of the North was or was not contemporaneous with the glaciation of the South.

Important changes of level occurred in the west of Europe before, during, and after the glacial epoch. The presence of the large mammalia, both in Britain and in Ireland, immediately before and immediately after the Ice period, proves pretty conclusively that at those times the British Isles were, for a certain period at least, both united with each other, and with the continent. A rise of some forty fathoms would unite England with the Continent at present, and a rise of a very little more would unite Ireland with England. The bearing of the Norway fiords and the Scotch lochs on the question of change of level has been alluded to in a previous chapter. These inlets have been cut down far below the sea-level, either by running water or by moving ice. This could only have happened when they were out of water, and to place them in that position now the land would have to be elevated in some cases more than six hundred feet. This would certainly unite Ireland with Scotland, and, if the elevation were carried far enough to the south, it would elevate all the English Channel and nearly all the North Sea into dry land. A curious confirmation of this exists in the fact that bones of the large extinct mammalia are occasionally dredged up far out in the North Sea. Many of the rivers of England also bear witness to a higher elevation of the land in Pre-Glacial times, inasmuch as their beds, now buried in mud, lie, some of them, as much as two hundred feet below the sea-level.

The great height to which the sands and shingles of the Interglacial period reach, proves that the land was at one time let down nearly fifteen hundred feet below its present level. This was followed by the second glaciation, and at the end of that period there is evidence that the south of Britain, at least, was considerably lower than it is at present. This is proved by the existence at various points along the south-western coast between Brighton and the Land's End, and also on the coasts of the Bristol Channel, of disconnected fragments of an old sea-beach, varying in height from twenty to forty feet above the present sea-level, and higher in the east than in the west. Though the land was apparently at a lower level, yet, nevertheless, the return of the great mammalia, and indeed of nearly all the present native fauna and flora, makes it evident that there was a connection with the Continent. It is quite possible that the sea had not at that time cut down the chalk of the Straits of Dover; and there was probably also a great accumulation of glacial *débris*, since removed; and these two causes combined were, no doubt, sufficient to make a land connection, across which both animals and vegetation gradually spread.

On the final emergence of the British area from the ice, while the general outlines of the land surface were the same, numerous minor but important modifications had taken place. The contour of the country was undoubtedly much more smooth and rounded, especially in the higher parts, where the ice first appeared, and where it lingered the longest. Not only were all the roughnesses worn down, but most of the loose surface soil and disintegrated materials with their associated plant and animal remains were either pounded and ground up into boulder clay and moraine *débris*, or swept bodily away. While the glaciers had, no doubt, deepened many of the valleys, both by sweeping out of them previously deposited alluvial matter and by excavating more deeply their rocky bottoms, there were, nevertheless, other cases in which valleys were either wholly or partly obliterated by being choked up with glacial clay. It thus happened that while most of the drainage reverted to its Pre-Glacial channels, some rivers, finding their valleys either wholly or partly filled in, took other directions, and excavated new valleys. An example of a Post-Glacial river valley is that of the Ouse, near Bedford. The river flows through a valley bounded by Oolitic rocks, capped with Glacial clay, and in the wide river valley is a hill composed of the same rocks, capped with clay containing remains of the mammoth and reindeer, and flint implements. The old valley of the Wear, near Durham, is choked up with boulder clay, and the river flows in part through a new channel, which crosses and recrosses the old one, and finally turns eastward, and leaves it altogether. The Tyne is another similar case. The Thames flows through its old valley, which is evidently very ancient.

All those deposits which are obviously posterior to the Ice age are called **Post-Glacial.** One special point of interest in them is derived from the fact that they contain clear evidence of the existence of man. We can hardly expect to find human relics in the Glacial deposits, because if man had been living in Britain at the commencement of the Ice age, he would have receded with the great mammals to a warmer region. We know that huge elephants lived here before the advent of the ice, and yet their bones are not found in the boulder clay. Consequently the absence of human relics from the boulder clay does not necessarily prove man's non-existence. The Pre-Glacial deposits likely to have contained his remains, if any, were practically obliterated by the ice-sheet in the glaciated regions; and in the case of deposits in other areas, which were not visited by the ice, it is not often easy or even possible to say whether they are Pre-Glacial or not. Occasionally, as in the Ray Gill fissure in the West

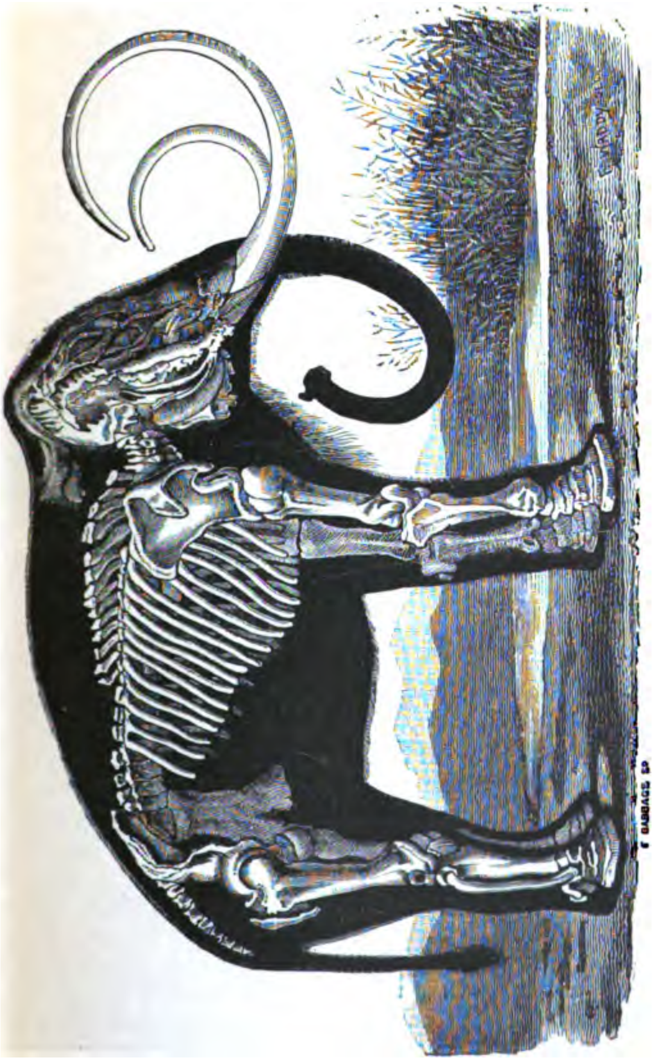


Fig. 288.—Mammoth, or Woolly-haired Elephant, whose bones, especially teeth and tusks, are common in our gravels.

Riding of Yorkshire, an assortment of Pre-Glacial *débris* is found forced into hollows and crevices of the rocks, but such materials, though they have yielded bones of the extinct mammalia, have disclosed no vestiges of man. Neither have such Pre-Glacial mammaliferous deposits as the Cromer Forest bed series yielded any evidence of his presence. Flint implements, rude in form and very roughly chipped, but unmistakably artificial, are found in the high-lying gravels which spread over a good deal of the higher ground of the south of England, and these are probably the oldest of human relics. They are also found in the patches of gravel and sand which still remain on the sides of river valleys and mark their ancient levels. Perhaps the best-known case of the occurrence of these archaic or *palæolithic* flint weapons in a river gravel is that investigated and recorded by M. Boucher de Perthes, in 1847. They were found in the valley of the Somme, in an old river terrace a hundred feet above the present stream, and were associated with the extinct mammalia. Some were very much worn, while others were quite fresh and uninjured, but they all agreed in being chipped only, and not ground or rubbed or polished in any way. Similar implements have been found in England in the high-level river gravels of the Thames, Ouse, and other rivers, and generally associated with extinct mammalian remains. As the rivers cut their channels deeper they became slower; and probably as all the ice disappeared they also became somewhat smaller, and the fine sediment, which before they had carried out to sea, was deposited, not only at their

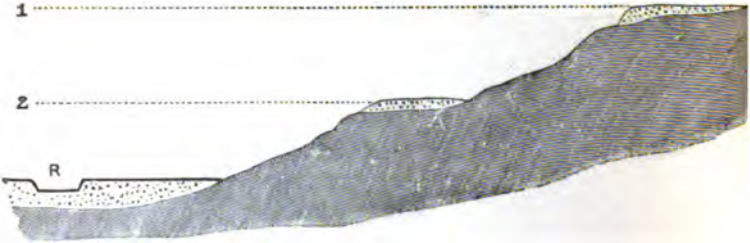


FIG. 289.—River Terraces.
1, original land surface; 2, later surface; R, the present river.

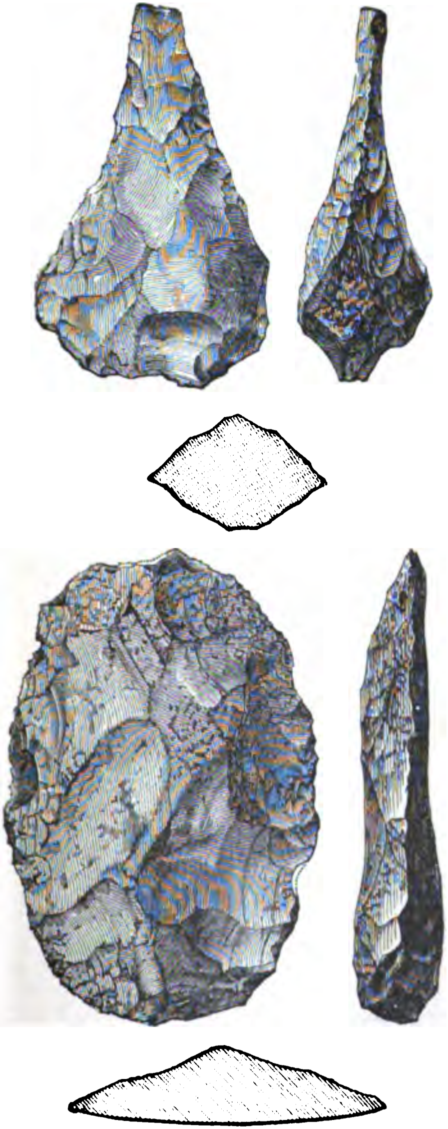


Fig. 290. Stone Implements: Palæolithic Age. Chipped into shape, but neither smoothed nor polished.

mouths, but some considerable distance up their valleys, forming the spreads of marsh and alluvium which now fringe the lower courses of our streams. The more recent origin of this material is shown by the fact that it rarely contains the remains of extinct animals, and that the stone weapons found in it are no longer palæolithic, but are well-shaped, more minutely and carefully chipped, generally ground to a good cutting edge, smoothed and polished all over, and often made of stone brought from a distance.

When the higher river terraces were being formed, the sea was engaged in forming those old beaches along the southern coast already mentioned, as well as others in the more northern parts of the country, and which were raised above the sea by subsequent elevation. Since then encroachments of the sea and the formation of bays and inlets have destroyed much of these old beaches; but, where fragments have been preserved, they are often found to be covered with a gravelly deposit, known as *head*, containing bones of extinct quadrupeds. Such a case may be seen on the chalk cliff near Brighton, where the raised beach is overlaid by a mass of gravel, known from its contents as the "elephant bed."

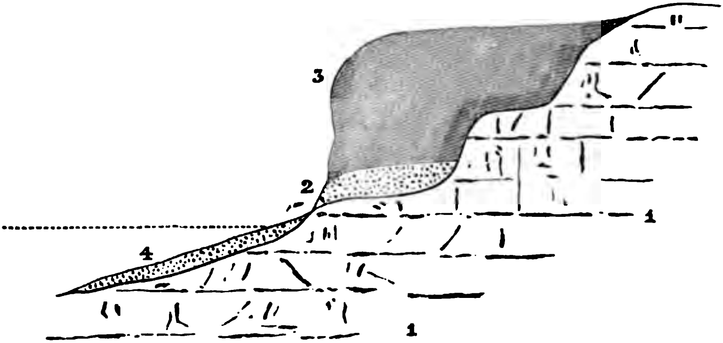


FIG. 291.—Cliff near Brighton.
1, chalk; 2, old beach; 3, "elephant bed"; 4, present beach. (Mantell.)

Information concerning these Post-Tertiary times may be gathered from the examination of the deposits contained in caves. Most of these occur in limestone strata, and are due to the solvent action of water. Sometimes, after the caves were formed, the streams worked their way down to a lower level, or, from various causes, diminished in size, or, perhaps, only flowed in time of flood, so that the caves became habitable for wild beasts, and even, in some cases, were occupied temporarily or permanently by man. At the same time the floor became strewed with loose material which fell from the roof and sides, and with the bones of the animals which frequented it, or those of their prey, and stones and bones were often all cemented together by the stalagmite deposited by the dripping or slowly trickling water, and perhaps occasionally buried under a layer of mud or clay brought into the cave by a return of the water. These causes, operating sometimes singly, sometimes in combination, have gradually filled up many caves, while their entrances have at the same time been hidden under the *débris* which has fallen outside from the cliff or slope of the hill. In this way, sealed up as it were, a history of the cave and its inhabitants has been preserved, the most recent at the top and the oldest at the bottom.

The *Victoria cave* in the limestone hills of the north-west of

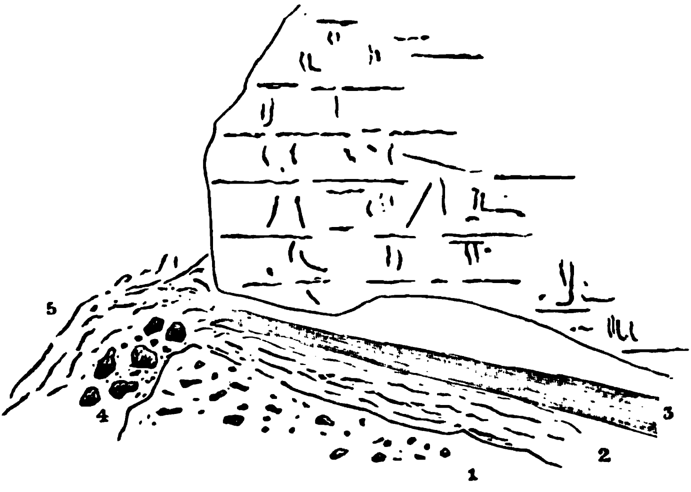


FIG. 292.—Victoria Cave.
1, lower cave earth; 2, clay; 3, upper cave earth; 4, glacial *débris* with silurian and other stones; 5, material fallen from the cliff above.

Yorkshire is a typical case. When first found it was nearly blocked up with a talus of material which had fallen from the cliff above, and it remained quite unknown until one day a dog was seen to follow a rabbit into it. When examined it was found nearly full of *débris*, but two feet below the surface an old floor was discovered strewed with charcoal, broken pottery, bones, with a miscellaneous assortment of bone pins, knife-handles, enamelled brooches, etc., of Roman or British design, and with them Roman coins. These circumstances suggest that it was used as a refuge or hiding-place by a Romanized British family after the departure of the Romans. Deeper down another layer of remains was found, bone harpoons and beads, flint-flakes, with bones of recent animals, evidently the remains of a period, remote historically, but still representing a time when men had learnt to fish, and, probably, to keep domestic animals. Deep down below this latter layer, and separated from it by a mass of laminated clay, are found the bones of the mammoth, hyæna, woolly rhinoceros, and other extinct animals, but no recognizable evidences of the presence of man among them. At the mouth of the cave, abutting against this lower "cave earth," and apparently subsequent to it, is a mass of glacial *débris* containing Silurian stones brought from a distance. If this glacial *débris* is in the position in which it was left by the ice, it is pretty certain that the lower cave earth takes us back to the Glacial epoch, and, perhaps, to the time before it.

Kent's Hole, in Devonshire, is another noted cave, in which three periods, somewhat similar to the above, are represented. In the lowest layer rude flint implements are mingled with bones somewhat similar to those in the lowest layer of the Victoria cave, thus giving us unmistakable evidence that man lived in this country at the time of the mammoth, cave-bear, and cave-hyæna. It is not possible, however, from the evidence at Kent's Hole, to say whether this was before, or during, or after the Glacial epoch.

Many other British caves, in the Mendips, in the limestone hills of Derbyshire, and in North and South Wales, give us similar information, more or less complete.

On the Continent there are famous caves with contents of the same character. In Belgium, at Engihoul and other places,

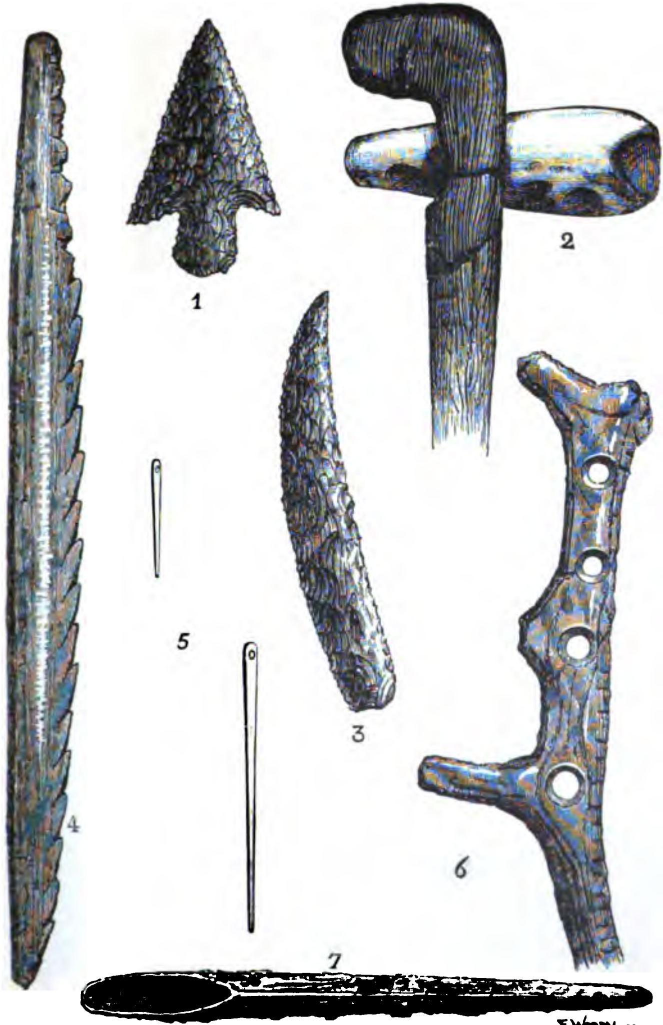


FIG. 293.—Implements of the newer Stone Age.
1, flint arrow-head; 2, stone axe with handle; 3, flint knife; 4, bone harpoon; 5, bone needles; 6, perforated horn; 7, spoon, probably for scooping marrow from bones.

human skulls have been found associated with flint implements and the usual extinct mammals. In Central and Southern France, in addition to the bones, tools, weapons, and ornaments of prehistoric man, specimens of his artistic powers have been found. One of these is a drawing of the mammoth, evidently from life, on a piece of its own ivory, while another represents a reindeer fight.

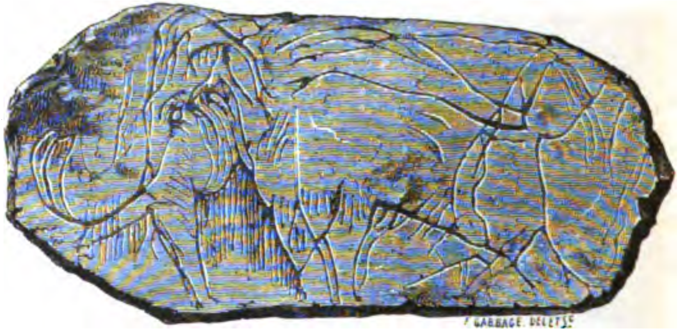


FIG. 294.—Mammoth scratched on ivory, found in the Madelaine Cavern in the Dordogne.

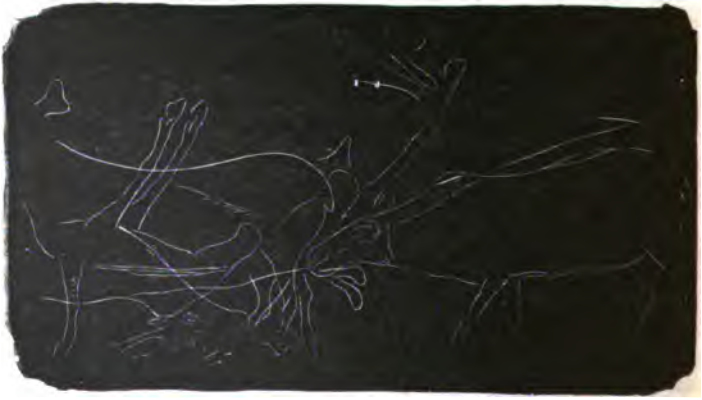


FIG. 295.—Reindeer fight, scratched on a piece of schist; found at Langerie Basse, France.

The extinct Post-Glacial fauna of Europe, whose remains have been so frequently alluded to, consist of two species of elephant, viz. *Elephas primigenius*, commonly called the mammoth, and *Elephas antiquus*; *Rhinoceros tichorhinus*, or the woolly rhinoceros; *Cervus megaceros*, the gigantic Irish stag, whose remains are often found in the Irish peat bogs (Fig. 296); *Bos primigenius*; and an extinct species of horse, *Equus caballus*; the cave lion, *Felis spelæa*; the cave hyæna, *Hyæna spelæa*, and numerous others.

The finer and more recent deposits formed by rivers have been already mentioned. They consist of clay, very fine sand, and calcareous matter, all in a very finely divided condition, and mixed in varying proportions. They often contain freshwater or land shells, such as *Unio*, *Cyrena*, *Helix*, *Pupa*, etc. Such a deposit is that which forms the only habitable and cultivable parts of Egypt, the narrow Nile valley and the Delta. It has been formed with extreme slowness by a thin film being annually deposited by the flooded river, not amounting to more than perhaps five or six inches in a century, and yet in some places it is now upwards of a hundred feet thick. A similar deposit occurs in some parts of the Rhine valley, and is known in Germany as *loess*. It is very fine, calcareous, pale-coloured, generally unstratified, and, between Bingen and Basle, is in places hundreds of feet thick. It seems to have been deposited under different geographical conditions to those at present prevailing, as the Rhine has in recent times cut its channel down to a much lower level. *Brick-earths* are somewhat similar in character, being composed of a fine admixture of clay and sand, deposited either by a slowly flowing muddy river, or by the surface action of rain slowly washing the finer portions of the soil down-hill.

River gravels, alluvial deposits, and caves have been more thoroughly and carefully examined in Western Europe than in any other part of the world, and, consequently, more is known of the fauna which immediately preceded that of the present day; but it is worthy of notice that the Post-Tertiary gravels and clays of Australia yield bones of extinct and gigantic marsupials allied to the native animals of modern times, while the great mammals of Europe, as well as remains of man, are entirely absent.

In South America remains of extinct species of sloth

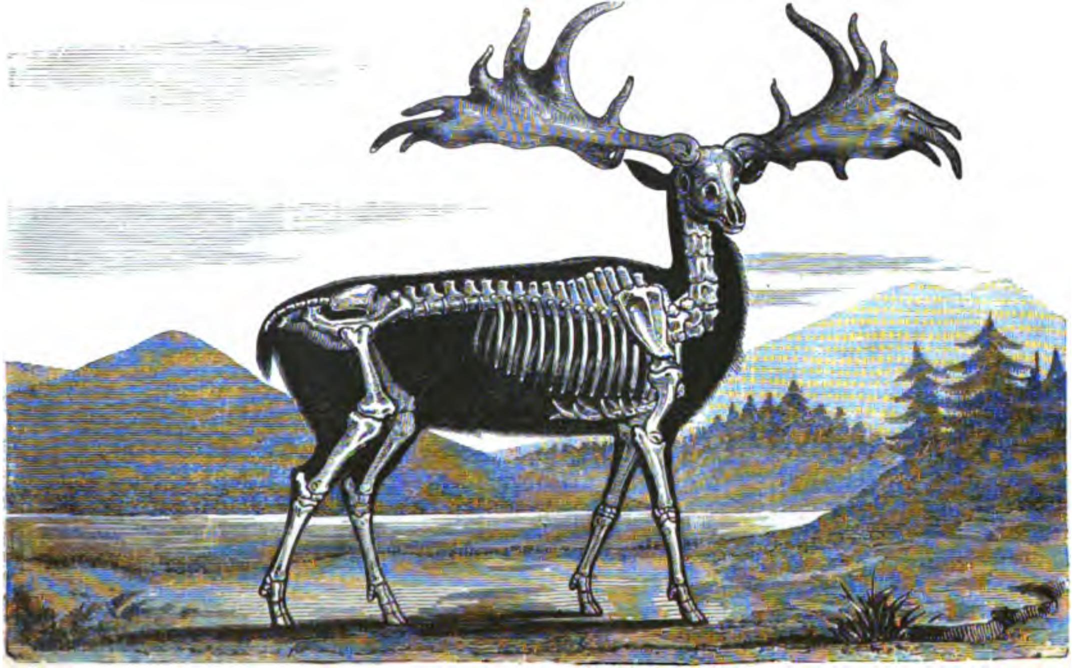


FIG. 296.—Gigantic Irish Stag (*Cervus Megaceros*) whose remains are often found preserved in the peat bogs of Ireland.

(*Megatherium*), armadillo (*Glyptodon*), llama and tapir, similarly allied to the recent native animals, are found in the caves and gravels of Brazil and La Plata; while in North America the remains of extinct and recent animals of the warmer regions, such as the edentata, tapirs, etc., are mingled with the remains of the wolf, deer, bison, and others of more northern climates.

These facts seem to show that, while, for some unknown reason, mammalia of a larger size than those living at present flourished all over the globe, yet the geographical conditions were such as to keep apart the three great masses of land, namely, the Old World, America, and Australia, and prevent their productions, both animal and vegetable, from intermingling. It also appears that the fauna of these three regions had assumed the special characters which they have at present, Europe-Asia being the home of the elephant, rhinoceros, lion, hyæna, etc.; Australia, of the marsupials; and South America, of the sloth and armadillo. In New Zealand, also, it is remarkable that the Post-Tertiary beds yield the bones of gigantic wingless birds, evidently the forerunners of the *Apteryx*, which has only recently been exterminated.

A remarkable series of relics of prehistoric times has been found in the Danish peat bogs. Here, as in the Victoria Cave, three distinct periods can be recognized. The lowest and oldest of all consists of stone weapons only, associated with the pine; the next of bronze implements and the wood, twigs, leaves, and acorns of the oak; the uppermost, and therefore the most recent, of iron tools and weapons, and remains of the beech, which is the predominant native tree of Denmark at the present day.

In Switzerland remains of dwellings erected on piles, out in the lakes, very similar to those at Brunei in Borneo and other places in the East Indies at the present day, have been discovered in a great number of localities, and notably in Lake Zurich. Many of these dwellings appear to have been destroyed by fire, and hundreds of articles illustrating the Stone and Bronze ages have been found in the mud of the lakes, together with the remains of still living wild and domestic animals. Investigators have been able to separate these remains into two ages: the Stone, when only wild animals were used as food, and the Bronze, when domestic animals were reared. Not only implements and bones, but carbonized corn and textile fabrics, pottery, and numerous other things have been found, sufficient to give a complete idea of their civilization and habits. The more recent of these Swiss lake dwellings, no doubt, bring us into historic times. Such dwellings, erected on piles in lakes for safety, appear to have once been very common, not only in Switzerland, but in the British Isles.

We thus see, in these Post-Glacial beds, man slowly emerging from the cave-haunting, wandering-hunter condition, through the pastoral and agricultural stages, into modern civilization and culture. During that period the great mammals which wandered about Europe gradually died out, partly, no doubt, under the attacks of man, and the country gradually assumed its present aspect. Rounded hills became rough and craggy under atmospheric action, while in some cases they have been protected under a covering of soil and vegetation; escarpments have been worn back a little further, headlands made more prominent by the encroachment of the sea on the more yielding strata, river valleys deepened in some parts and in others gradually filled with alluvium, and the moorlands clothed with peat. In later times, also, the action of man as a modifying agent has been very important. He exterminates noxious animals and plants, encourages those which are useful to him, clears the forests, drains marshes, transplants both plants and animals from one side of the world to the other, dams up rivers, and drains lakes.

SUMMARY.—1. The gradually increasing cold of the Pliocene times culminated in the Glacial period, when the cold-temperate regions of the northern hemisphere were covered with ice, as is proved by the presence of boulder clay, moraines, scratched and smoothed rocks, and erratic blocks.

2. The general disposition of the boulders and direction of the striæ proves that, with local modifications, the ice-sheet moved southwards, and reached, when at its maximum, to the Thames basin.

3. There are proofs that, at times during the Ice age, and

after it, the country was to a large extent submerged, though it is certain that, after the retreat of the ice, the British Isles were, for a time, united to each other and to the Continent.

4. The effect of the ice upon the country was to sweep off most of the surface material, round the outlines of the hills, and fill up, and in a few cases permanently divert, the rivers.

5. It is not proved that man existed in England before the ice age, although his remains have been found in positions which suggest his "interglacial" existence. Outside the glaciated regions it is difficult and generally impossible to say whether a deposit is *Pre-*, *Inter-*, or *Post-*Glacial.

6. Localities interesting on account of their connection with the question of the antiquity of man are, the Victoria Cave, Kent's Hole, Engihoul, the Danish peat bogs, the Swiss Lakes, and the Somme Valley.

QUESTIONS.

1. What are the chief evidences that there were interglacial periods?
2. Describe the ice-flow over the (*a*) Irish Sea, (*b*) North Sea, and state the evidence on which the conclusions are based.
3. What are *eskers?*
4. Describe the condition of Switzerland in the Ice age.
5. What proofs are there that England was united to the Continent after the ice had disappeared? How was it probably disconnected?
6. What do we learn from the marine shells on Moel Tryfan and the raised beaches of the South Coast?
7. Give examples of permanent changes in the courses of rivers which were brought about by the ice, and explain the process.
8. Discuss the question of the antiquity of man in connection with the Ice age.
9. Describe Kent's Hole in its bearing on the antiquity of man.
10. In what way has man modified the appearance of the country and its fauna and flora?

CHAPTER XXX.

THE DISTRIBUTION OF LIFE ON THE EARTH IN TIMES PAST AND PRESENT.

THE whole world is divided by naturalists into six regions, each of which contains a well-marked assemblage of animal life, very many species and numerous genera being absolutely and entirely confined within the limits of one particular region. The six regions are (1) the *Holarctic*, comprising the whole of the central and northern portions of North America, Europe, and Asia; (2) the *Neotropical*, which includes Central and South America; (3) the *Ethiopian*, Central and Southern Africa; (4) the *Oriental*, South-east Asia; (5) the *Australian*, and (6) the *Polynesian*. There are subordinate transition regions in the *Mediterranean* countries, the *East Indies*, and *Mexico*. The great regions are themselves divided into *sub-regions*, and the latter into *provinces*, etc. The sub-regions contain fewer indigenous genera and species, and the smaller divisions fewer still; but each has its own special and peculiar features, and is characterized by the absence of some forms of life, the presence of others, and the exclusive possession of at least some species. This state of things is largely the result of local climate and physical peculiarities, which favour or discourage the spread of the various species in different directions. That this is not the sole cause, however, is obvious when we consider that in many countries new species either of animals or plants from another region thrive exceedingly when introduced. It is quite certain, for instance, that the sheep never set foot in Australia, the horse in New Zealand, or the pig in the West Indies, till introduced by man in recent times; and many other instances, both in the animal and vegetable kingdom, could be given.

Under these limitations, each species has established itself in an area, large in some cases, small in others, which is called its *range*. As a rule, those organisms which are simple in character have a wider range than those which are more complex and specialized. Now, when we come to compare living animals with those whose remains are embedded in the rocks, the following points strike us: firstly, that many kinds of animals have become extinct; secondly, that while there is a general agreement, yet many changes of detail in the range of various genera and species have occurred even in quite recent geological times; and thirdly, that when we go far back there seems to be no trace of the present natural history regions. The first point needs no special illustration here. The second is obvious when we consider that even since the Glacial epoch mammals, now extinct, of the same genera as the modern elephant, lion, tiger, and hyæna, lived in England, while none of their modern representatives are now found in Europe; and going a little further back we find remains of animals which are now not found in the same region mingled together in the Pliocene deposits of India and Japan, including such creatures as the giraffe and ostrich, which are now confined to Africa. With regard to the third point, we need go back no further than the London Clay period, when all sorts of tropical plants and animals flourished in what is now England.

After William Smith's great discovery of the fact that each group of strata in England contains its own special and peculiar fossils, by which it can be recognized and identified, great progress was made in the study and grouping of the fossiliferous rocks. Where there was an unusually marked difference between the fossils of two formations, a line was drawn which was made the division between two geological systems. It was observed, for example, that the Lower Tertiary beds contain no fossils which are common to the chalk upon which they frequently rest; and to explain this, it was supposed that some overwhelming catastrophe had occurred after the deposition of the chalk which brought to an end all organic life, and that with the inauguration of the Tertiary period a new set of plants and animals was created and a fresh start made. These catastrophes and special creations were freely introduced wherever necessary, but as geological research went on many difficulties presented themselves. These were caused by the gradual discovery of strata which to some extent bridge over the gaps and contain an admixture of the old forms and the new; and so it became necessary to imagine minor catastrophes which annihilated some species and spared others, and minor special creations which introduced a few new forms, instead of a complete set.

Another mistake which was made in these early times was the tacit assumption that the whole world constituted only one natural-history region, and that the plants and animals of the period were the same everywhere. This was disproved by the discovery that, although in a limited area, like England, strata may be found in one part which contain an exactly similar suite of fossils to those in another, yet, when more distant regions are examined, it is impossible to exactly match strata in this way, and the further they are apart the greater is the difference. It is, in fact, quite impossible to say whether two sets of strata which are any distance apart were deposited contemporaneously or not, and the further they are apart the greater is the chance of error. Two deposits whose fossils are quite unlike may be contemporaneous, one being, for instance, a marine limestone, the other a fresh-water marl; or, to take a modern case, two deposits of mud, one at the mouth of the Thames, and the other at the mouth of the Niger. On the other hand, similar fossil contents do not necessarily imply contemporaneity. A prehistoric mud-bank in the Mediterranean will contain the same shells as one forming to-day, and even a Pliocene deposit in the same region would vary very little. If two far-distant strata closely resemble each other as regards fossil contents, it would be considered a proof that they were not contemporaneous rather than that they were, inasmuch as we should not expect the same group of species to be living in localities very far apart at the same period, but rather that, through lapse of time and geographical change, the species which once occupied the one area had migrated to the other. Professor Huxley has proposed the term "homotaxis" as a substitute for "synchrony" or "contemporaneity" for geological purposes. The term, which means "similarity of arrangement," merely implies a corresponding position in the geological series. The fauna and flora of the English Devonian rocks are *homotaxial* with those of Devonian strata elsewhere, although, for anything we know, they may or may not have been *contemporaneous* with each other, or with Silurian life in one part of the world, and with Carboniferous in another.

The doctrine of catastrophes was gradually replaced by the theory that the life existing on the earth at any particular point of time was derived by direct descent from previously existing life. Various explanations were offered of how it could have happened that old forms were continually disappearing and new forms appearing, but the most satisfactory, and the one which is now practically accepted universally by naturalists, is that of Darwin, which was first published, under the title of "The Origin of Species," in 1859. The theory is briefly as follows: The young of every species, both animal and vegetable, while resembling their parents in a general way, yet differ from each other in almost every respect, some of the variations giving the individuals an advantage, and others a disadvantage, in their power of procuring food, withstanding the weather, defending themselves from enemies, and so on. With this is to be considered the fact that young are produced in very large numbers, and that the earth is quite unequal to the task of rearing and supporting them all. Hence, in the severe competition which takes place, the weakest "go the wall" and the strongest survive, and transmit to some extent their advantages to their progeny. This continual elimination of the weakest and preservation of the strongest was called by Darwin "natural selection," and is the keystone of his theory. It is believed that in this way the various members of one species would generally differ more and more from each other, until at last the differences would be so great that they would no longer be considered as members of one species, but of several. Thus the original *species* would become a *genus*, with several species belonging to it; and it would probably happen that, owing to variation in one direction or another, no individuals would remain which would resemble the members of the original species, which in that case we should say was *extinct*. This theory, therefore, offers a simple solution of the mysterious disappearances and appearances which were so puzzling. Extinction might happen in the manner indicated above, or it might be that the members of some species, genus, or even order, died out and left no descendants, owing to inability to vary beyond a certain point, thus being crushed out in competition with other species. This was probably the case with the Ammonites, with the gigantic reptiles of the Lias, and many others. Variation, under the influence of natural selection, would not stop with the conversion of species into genera, genera would be converted into orders, orders into classes, and so on. In fact, the Darwinian theory supposes that from some one simple form of life, by the action of natural selection, the whole of the life of the earth, both animal and vegetable, recent and extinct, has been evolved. As we cannot conceive of any life existing on the earth before it was cool enough for the deposition of aqueous rocks, it might be thought that if the theory were true we should find full evidence of it in those rocks; but this is not so. The very earliest of the stratified rocks have probably not come down to us at all, and the oldest known are so metamorphosed that all traces of any fossils they may have contained have been quite obliterated. We do not, therefore, find a complete history of life in the rocks, especially of its early development; the oldest fossiliferous rocks presenting to our view a series of remains which are very far removed from the primordial conditions, for we have in the Cambrian fully developed species of the highest animal subkingdoms except the vertebrata. If the Darwinian theory is true, therefore, it is obvious that there must have been life on the earth for a very long period before the deposition of the Cambrian rocks, though we know practically nothing about it. In fact, the Cambrian period must apparently be further removed from the time when life originated on the earth than the present time is from the Cambrian. The "imperfection of the geological record" also offers great difficulties to the full testing of the evolution theory, though as time goes on the record becomes less and less imperfect, and, if we may judge from the past, many gaps will be filled and missing links supplied in the future.

Among the great changes in animal and plant life which the rocks disclose, there is also evidence of the "persistence of types." Many Silurian corals and mollusca have persisted with only specific, not generic changes; and the same may be said of Oolitic conifers, Carboniferous insects and plants, Mesozoic crocodiles, and numerous others. Thus we find that, while very many species have been blotted out, fewer genera and still fewer orders have disappeared. The chief extinct orders are the rugose corals among the cœlenterata; the *Cystidea* and *Blastoidea* among the echinoderms; *Trilobita* and *Eurypterida* among crustacea; *Labyrinthodonta* among the amphibia; and *Ichthyosauria*, *Pterosauria*, *Plesiosauria*, and *Dinosauria* among reptiles. No orders of fishes, birds, or mammals are extinct.

The changes by which new species are evolved are slow and imperceptible, but the disappearance of species, especially when they compete with man, may be actually observed. As examples, may be mentioned the *dodo* of Mauritius, the *solitaire* of Reunion, and the *moa* of New Zealand. The beaver, the giraffe, the zebra, and many others are on the decline, and will probably soon cease to exist.

When we consider the extensive geographical changes which evidently have been continually occurring in past times, it is not difficult to understand why the deposition of the various strata one over the other in the same locality should be accompanied by the entombment of a varying assortment of animal and vegetable remains. A very trifling depression or elevation might cause two very different marine faunas to intermingle and encroach on one another, and so produce great changes. For example, a slight lowering of the east of the Mediterranean would mingle the waters of the Levant with those of the Red Sea, and would cause considerable changes in the fossils now being embedded at the mouth of the Nile, and that without any change in the physical character of the deposit which would afford a clue to what had happened. A gradual shallowing of the waters of a sea would bring littoral mollusca into contact which had before been separate. This may be illustrated by supposing the North Atlantic to gradually become shallower through the slow upheaval of the bottom. The effect of this would be finally to bring Iceland and Scotland into communication, and to mingle to some extent their respective faunas. Changes in drainage areas would bring about changes in the organic matters brought down by rivers and embedded in their deltas. The slow shallowing of water by the formation of limestone gradually unfits it for the existence of limestone-forming agents, and prepares the way for deposition of mud or sand with such organisms as exist in shallow water on muddy or sandy bottoms. No doubt this is why we find thick beds of limestone with brachiopods, corals, and encrinites, such as the carboniferous limestone, overlaid by beds of shale and grit, in which most of the characteristic fossils of the limestone are absent. In most cases the changes are gradual, and the old fauna either slowly degenerates and dies out, or emigrates, or adapts itself; but there are cases where the accumulation of the remains in all stages of growth is so enormous as to suggest some sudden local catastrophe. Such occurrences have been frequently observed, and are brought about in various ways. The rapid melting of a large fall of snow may fill a bay with fresh water and kill many of its marine inhabitants. Heavy rains have the same effect. Earthquake disturbances have been known to leave banks of crabs and molluscs high and dry out of water. Exceptional evaporation in lagoons and estuaries in hot seasons will kill all the fish and other inhabitants.

The amount of change in the distribution of life during even the most recent geological epochs is manifest when we consider the relationship which the fossils of the European Miocene, Pliocene, and Post-Pliocene bear to existing species and genera. In the Miocene we have plants whose nearest representatives are found in the tropics of both the Old and New Worlds, together with species allied to the gigantic pines of the Rocky Mountains, while the mollusca are also of tropical genera. In the Pliocene the plants and invertebrate fauna are of genera now found in Europe, though not always in the same area, while in the Post-Pliocene they are nearly all of local and still-existing species. The mammalia of the Miocene and Pliocene consist of numerous species of the ungulata, carnivora, and proboscidea, all extinct, and of genera many of which are not now found in Europe; while the Post-Pliocene mammals consist of a mixture of extinct and living species, though less local in their character than the invertebrata.

In the comparatively isolated areas of Australia and South America there is a marked connection and resemblance between the extinct mammals of the Post-Pliocene epoch and those living in the same regions at the present day. No proboscidea or Old World genera of carnivora occur; in South America the modern sloth is represented by the gigantic *Megatherium*, the armadillo by the *Glyptodon*, the llama by the *Macrauchenia;* while in Australia the extinct species are similarly allied to the existing kangaroo, wombat, etc. This peculiarity is evidently due to geographical isolation, and contrasts with the Post-Pliocene and Pliocene mammalian remains of Europe and Asia, where there has been greater freedom of movement.

The following generalizations have been deduced from the study of the distribution of living and extinct plants and animals.[1]

1. The difference between living and extinct faunas of any locality varies as the distance in time; that is to say, the more ancient the fauna, the more unlike it is to that existing at present.

2. In passing all the forms of life in review from the earliest times, it is found that the diversity in organization increases with the time, and that the highest types are on the whole the most recent.

3. The chronological order in which the various types of life appear often recalls the phases of embryological development.

4. Extinct types do not reappear.

5. The range of many individual species appears to have been greater in ancient times.

6. The wider the range of a species in space, the wider the range in time, *i.e.* a species which is found in widely separated strata is likely to survive through a long period of time.

SUMMARY.—1. For natural-history purposes the whole earth is divided into six regions, with three subordinate regions. Each region is divided into sub-regions, provinces, etc.

2. The "range" of a species depends partly on present climatic and geographical conditions, and partly on what has preceded.

3. The old ideas that in geological times life was practically alike all over the world, and that changes were due to catastrophes, were replaced by the doctrine of evolution and uniformitarianism.

4. According to this doctrine all the present life of the earth is directly descended, through successive modifications due to "natural selection," from some simple form of life, although the records of the earlier stages are obliterated.

5. Among the changes of past times, the types remain. The great divisions and subdivisions of the animal kingdom, even to the orders, are recognizable in very ancient times, and very few have disappeared.

6. Very slight geographical changes, such as the removal of land-barriers between two seas, changes in drainage areas,

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[1] Pictet.

shallowing or deepening of the ocean, bring about marked changes in the fauna and flora; and instances of such changes may be seen when we compare the distribution of life in Tertiary times with that of the present day.

QUESTIONS.

1. Explain the principle on which the great natural-history divisions and their subdivisions are based.
2. What various conditions determine the range of any given form of life? Why are there no native crocodiles in Europe or native sheep in Australia?
3. What changes of opinion have taken place during the last hundred years with regard to the life of past and present times?
4. Explain briefly the Darwinian theory.
5. What is meant by *homotaxis* and *persistence of type?*
6. In what two ways might a species become extinct?
7. Why does geology throw very little light on the earlier stages in the evolution of the diverse forms of life?
8. Give illustrations of the manner in which (1) a fresh set of organic forms might be introduced into any given area, and (2) a particular set might be transferred from one locality to another.
9. Contrast the (*a*) Miocene, (*b*) Pliocene fauna and flora of Europe with the present.
10. Enumerate the leading generalizations deduced from the study of distribution.

CHAPTER XXXI.

MINERALS AND MINING.

THE mineral materials which are extracted from the rocks are either obtained from open quarries or from mines. A mine is sometimes the continuation of an open quarry, the desired stratum being followed underground without the removal of the overlying material, or it may be a shaft sunk vertically downwards to a deposit buried deep below, which is then worked in convenient directions from the bottom of the shaft. The mineral wealth of the earth is obtained from both the aqueous and igneous rocks. In the former it may be an interbedded stratum, as the coal beds and many of the iron ores; and in both aqueous and igneous rocks the mineral matter may be in a crack or fissure which penetrates the rock.

The most important minerals which occur in the interbedded condition are coal, iron, salt, and gypsum, and they have already been referred to and their probable origin explained in connection with the systems in which they are found.

The coals of England and Western Europe are found in the Carboniferous system, but in other parts of the world other systems yield abundant supplies. The coals of India are mainly derived from the Oolitic rocks, and many of the beds are as thick as any we have in England; and there are Oolitic coal seams in Virginia thirty or forty feet thick. Even in Scotland, at Brora in Sutherlandshire, there are two Oolitic coal beds three or four feet thick, which have been largely worked. In Transylvania there is a coal-field situated in the Tertiary rocks, associated with unmistakable Tertiary fossils, which yields excellent coal from very thick seams. All these coals are, like those of England, associated more or less with ironstone. In Hungary coal is worked in the Cretaceous rocks. These instances will serve to show that the conditions which brought about the coal deposits of our Carboniferous system were not absolutely unique; they recurred in other parts of the world during other periods. In the case of the Dover boring, some ten seams of coal, from one to four feet thick, have been met with at depths varying from 1,100 to 2,200 feet; but until fossil evidence was forthcoming it was by no means certain that they belonged to Carboniferous rocks.

Coal is almost invariably got by sinking a shaft through the superincumbent strata down to the workable coal. As these shafts are very expensive, great judgment is required in fixing the most suitable position, and in calculating the depth at which the coal will be found. To this end a thorough knowledge of local geology is required, the thickness of the various beds, the direction and amount of the dip, and also very particularly, full information as to the faults intersecting the neighbourhood. As these shafts are sunk below the level at which the rocks are saturated with water, great expense is generally incurred in keeping out the water as much as possible by lining the shaft so as to make it watertight, and powerful pumping machinery is also provided. When the workable coal seam is reached it is cleared away from the bottom of the shaft, and then followed in all directions, pillars of the material being left at intervals to support the roof. Very often two shafts are sunk some distance apart, and then they are connected together below as soon as possible. This secures good ventilation and greater safety.

Many of the coal seams dip downwards and finally pass out of reach of mining operations. Most of our coal-mines are less than a thousand feet in depth, but some are twice as deep, and some in Belgium are even three times; but the expense of lifting the coal so far, and more particularly the expense of pumping water continually, renders these deep workings hardly remunerative.

The chief iron ores are *magnetite* (Fe_3O_4), abundant in Scandinavia, Elba, India, etc., but rare in England; *hæmatite* (Fe_2O_3), found in beds up to thirty feet thick in the carboniferous limestone of Ulverston; and the *clay carbonate* of the coal measures. The latter are often worked in the same mine as the coal, while the Liassic carbonate of Cleveland is worked largely in open quarries. The iron ores of these and other English localities are practically inexhaustible.

Lenticular masses and thin sheets of various ores, chiefly of iron, often occur in crystalline schists, and iron in a diffused condition is very abundant in certain basalts; but the greatest quantity and variety of all metallic ores except iron are found in fissures and veins which ramify through the rocks, both stratified and unstratified. These ore-bearing fissures are, for the most part, due to the same forces as produce faults. Indeed, many of them are faults; but, as a rule, instead of the two faces of the fractured rock being rubbed and ground against each other, they stand more or less widely apart, and the cavity is filled up with broken rock fragments, mineral matter, and metallic ores. These fissures generally strike across the rocks in the direction in which they have been elevated; they are often traceable for miles at the surface, and they descend to an unknown depth. The fissures are very irregular in section, being wide in some places and narrow in others; and, in limestone rocks especially, large cavities occur, which have been in the first instance dissolved out by water, and have then been filled in with mineral matter. The chief minerals which are not worked for the sake of metals are quartz, calcite, heavy-spar, and fluor-spar. When these are in a close compact condition they are known as *veinstuff*, but if in well-marked crystals they are called *spar*. Sometimes one mineral fills up the fissure completely; in other cases the two sides of the crack are lined with layers of different minerals, or the same mineral in different states, generally in the same order, and which finally meet in the middle. Sometimes hollow cavities still remain with their interiors lined with crystals; in other cases the cavity is partly filled with broken matter from its walls, cemented together with some mineral, and converted into a breccia. The associated metalliferous ores also occur in a great variety of forms. They may be merely minute grains or thin threads and strings, as is frequently the case with native gold, in laminæ and bunches (copper), in crystal-lined cavities (galena), or in layers intercalated with other minerals. As regards their chemical composition, gold is always, and silver and copper frequently, uncombined or native; iron, copper, silver, and tin occur as oxides or carbonates; lead, zinc, copper, and antimony as sulphides; silicates and chlorides of various metals are also frequent.

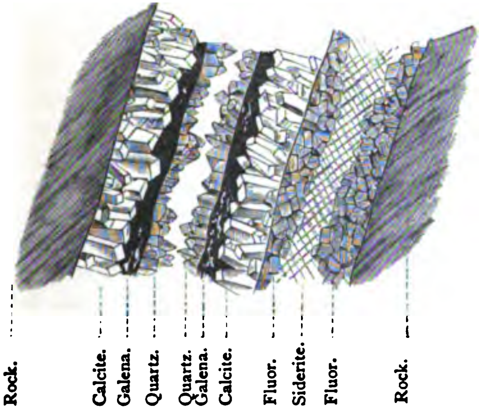

FIG. 297.—Section across a lode.

The largest and most continuous veins occur in lines of fault, but generally the downthrow is not very great. As they are worked downwards the ore sometimes get poorer or less in quantity, and the fissure contracts, so that it does not pay to follow it further down; but, as a rule, the fissures extend apparently far beyond the limits of profitable or even possible mining operations. In metalliferous districts, such as Cornwall, many of these fissures are nearly or quite parallel to one another, are evidently due to the same forces, and were probably formed at about the same period; and it generally happens that the mineral contents of such related veins are similar. In Cornwall, for instance, the most important series is roughly parallel to the greatest length of the county, and is connected with the axis of upheaval, and they are the fissures which contain the copper and tin ores. Other fissures, known as "cross courses," almost at right angles to these, sometimes contain galena and iron pyrites, though they are more often barren. The nature of the surrounding rock seems to exercise an influence on the deposition of metallic ores. In Cornwall it has been noticed that a copper and tin lode is rich in copper where it traverses slate, and in tin where it traverses granite, and the deposits of galena in the Carboniferous rocks of the north are generally rich in the limestone and very poor in the shale. Sometimes a lode wholly or partly splits up into a confused mass of veins, or even scattered particles, the mineral matter being thus dispersed through the mass of the rock, instead of being concentrated in the usual way, and if the ore is present in a sufficiently large percentage the whole rock is worked out. The typical cases of this occur in the Erzgebirge, and are there called *stockwerks*, and the structure is also common in Cornwall. Indeed, it has been stated that half the Cornish tin is got from such deposits. In Norway some of the crystalline rocks are impregnated with metallic sulphides in an exceedingly finely divided condition, and are very prone to decomposition on that account. These metallic tracts are not apparently connected with lodes or veins, but they form zones or lenticular masses, and are known as *fahlbands*.

The Carboniferous limestone in the north of England is much faulted, and the faults are filled in with calcite and fluor, with more or less galena generally forming a thin deposit between the spar and the rock wall. In Cumberland large horizontal masses, ranging up to several feet in thickness, are sometimes found between the limestone strata.

Some veins consist almost exclusively of quartz, and it is in such veins that the precious metals are disseminated in the native condition.

Among important and interesting metalliferous regions the following may be mentioned. The mercury of Almaden occurs as cinnabar, or sulphide of mercury, lying among quartz in fissures traversing Upper Silurian rocks, and, though rare elsewhere, is remarkably abundant at this locality. The Comstock lode in Nevada, U.S., is the richest silver deposit in the world. The lode is four miles long, in places more than a hundred feet thick, and is worked to a depth of nearly three thousand feet. The ore consists principally of native silver, and the sulphide of silver, and lead. On the shores of Lake Superior, Cambrian and Silurian strata are penetrated with large quartz veins which yield enormous quantities of native copper. The silver mines of Mexico and of Peru yield sulphides of silver from quartz and other veins in rocks, chiefly of Carboniferous age. The gold of Australia occurs disseminated in fine particles, in veins of pure quartz traversing Palæozoic rocks.

From what has been said, it is evident that most metalliferous ores are found in fissures traversing the older rocks, though there are cases of Tertiary lodes, as, for instance, those of gold, silver, and lead in Transylvania. As a rule they are associated with eruptions of igneous rocks, and with evidences of metamorphic action.

The exact method by which many mineral deposits have been formed is at present a mystery; but careful observation of facts justifies certain deductions. From the fact that the nature of the rock influences the deposit, we may infer that in some cases it has been either wholly or partly dissolved out of the adjacent rock, and deposited from solution in the fissure. Many of the ores, however, are quite insoluble in water under ordinary conditions; but the almost invariable presence of igneous and metamorphic rock suggests that they have been exposed to intense heat; and it has been proved by experiment that many substances which are insoluble, or nearly so, even in boiling water, become soluble when, under great pressure, the temperature of the water is raised above its ordinary boiling-point. In this way crystals of quartz have been obtained; and in the presence of alkaline carbonates, crystals of heavy-spar, fluor, and carbonate of iron have been formed. In the south of France there is a case where thermal waters, by acting on a mixture of Roman coins and metal ornaments, have formed a great variety of copper and lead compounds. In Nevada, U.S., there are hot springs, issuing from fissures extending through granite, which have coated and, in places, quite filled up the fissure with silica, containing, in one case, iron oxide, in another oxides of iron and manganese, with traces of iron pyrites and copper, and, in a third, sulphide of mercury. Near San Francisco cinnabar has been deposited under similar conditions. An analysis of the waters of thermal springs also discloses the fact that they may contain, in solution, traces of nearly all the ores and minerals found in lodes.

There cannot, therefore, be much doubt, although the process cannot always be fully explained, still less imitated artificially, that these mineral deposits are due to intensely heated water permeating the rocks, or rising up from below, and bringing with it the various lode ingredients in solution to deposit in cavities and fissures wherever it can find room. The successive layers of different minerals which are found in many lodes were no doubt brought about by changes in the subterranean conditions, which either caused the water at different times to come from different directions, or which, by raising or lowering its temperature, altered its solvent power for various substances. The native metals were no doubt brought into their present position as soluble salts, and, after being deposited, were reduced to the metallic state. That this must sometimes occur is rendered certain by the discovery in Peru of the fossil bones of an extinct mammal, with threads of native copper filling the pores.

In the course of sub-aerial denudation, mineral veins and lodes are weathered, disintegrated, and swept away with the rest of the materials of the earth's surface, and their contents become mixed with the surface and valley deposits of clay, sand, and gravel. Consequently the presence of mineral lodes in the rocks of a drift-covered country is generally indicated by the discovery of mineral fragments in the drift. Much gold, both in Australia and California, has been got from thick sands and gravels of this kind. It is generally found deep down in the deposits, and especially at the very bottom, where the gravels rest upon the solid rock. This is due to its superior specific gravity, the heaviest material sinking to the bottom under the action of the water by which the deposit was formed. Except in the case of gold, metalliferous surface deposits are not, as a rule, actually worked for metals, but, in exploiting a country for mining purposes, they are carefully examined and followed up till the lode is reached from which the fragments of ore are derived. This is often a tedious and expensive process, as it is necessary, for the reason above given, not merely to examine the surface, but to sink pits into it to some depth. When the lode is at last struck, its direction across the country has to be determined. This is done by cutting trenches across its supposed direction. When its position has been satisfactorily settled, trial pits are dug into the lode, in order to ascertain its character and the chances of profitable working. All this is very speculative, and thousands of pounds may be expended without any return. Owing to alteration through weathering and denudation, lodes are frequently much impoverished near the surface, and it is necessary to go some depth before their real character can be ascertained. In a few cases, however, the lode is both wide and rich, and ore can be at once extracted in open workings, as in the case of the iron of Elba and Dalecarlia. This, however, is quarrying rather than mining, and is exceptional. Should the lode be promising, its dip and general position underground are ascertained as nearly as possible, and a shaft is sunk into it, and workings are commenced in the lode in both directions. The water difficulty soon presents itself, inasmuch as any shaft sunk into the rocks below the saturation level becomes, not a mine, but a well, unless the water is removed as fast as it enters. As metal mining is generally carried on in hilly regions, it is frequently possible to drive a horizontal or gently up-sloping tunnel from the side of a hill into the bottom of the shaft. This is called an "adit," and serves the purpose of a drain, to carry off the water, and also, sometimes, as an exit for the minerals. As the work proceeds, other shafts are sunk, some from the surface, others from the underground workings, their positions being determined by the character of the lode, the two objects being the economical drainage of the mine and the extraction of the ore. A metal mine, therefore, is much more complicated and irregular than a coal mine, and cannot be calculated and planned out beforehand; and it is also, for the same reason, much more speculative and risky, from a financial point of view. Metal mines have, however, some advantages over coal mines. There is very little difficulty about ventilation, as it scarcely ever happens that there is any generation of escaping gas, and for the same reason, therefore, lighting is easy, and blasting can be carried on with comparatively little danger. When the lode is very wide, it is sometimes necessary to arrange very massive timbering to keep it from crushing together or falling in after the ore and vein-stuff have been removed, and careful supervision is required in such cases, as the water often causes the timber to decay rapidly. In expelling the water from a mine, care has to be taken that it does not find its way back, either into the mine from which it has come or into any adjacent works; and where mines are numerous, as in Cornwall, it is sometimes found necessary to construct an adit of great length, which shall pass through a series of mines, and remove the water from them all in common.

From motives of economy as little vein-stuff is brought up as possible, and that which is associated with the ore is removed by crushing and washing at the mouth of the mine. Owing to the intricacy and irregularity of metal mines, and also often to their greater depth, the lifting of the ores and the passing of the men up and down is a serious difficulty and expense. In the case of the very deep mines a miner would have to supplement his day's work by the tedious and exhausting process of climbing up half a mile of ladder. This is in many cases avoided by the use of ingenious contrivances called *man-engines.* One of the best consists of a double series of parallel vertical wooden shafts, with steps for standing on at intervals, and so arranged that they are continually rising and falling through a fixed interval, one beam rising while the other falls. A man wishing to go down places himself on a step of the beam which has just risen to the surface, this immediately descends about twenty feet. He then steps off it on to a step on the other beam which has just risen, and is carried down by it another twenty feet, and so on. To ascend he reverses the process. This method can, of course, only be used in mines, or sections of mines, where the descent is vertical.

The following is a list of the chief metallic ores found in England, with their chemical composition :—

Iron ...	Fe_2O_3 = hæmatite ; red hæmatite ; red oxide ; if nodular, kidney ore ; if crystalline, specular iron, or iron glance ; if combined with water, limonite, brown oxide, ochre, bog iron ore.
	Fe_3O_4 = magnetite.
	$FeCO_3$ = spathic iron ; siderite ; chalybite ; if mixed with clay, clay-ironstone.
Lead ...	PbS = galena.
	$PbCO_3$ = cerussite.
Zinc ...	ZnS = blende.
	$ZnCO_3$ = calamine.
Copper ...	CuS = copper glance.
	$CuFeS_2$ = copper pyrites.
Tin	SnO_2 = tin stone, cassiterite.
Manganese	MnO_2 = pyrolusite.
Gold... ...	native in small quantities.
Silver ...	associated with galena.

SUMMARY.—1. Minerals are got from interstratified deposits, or from fissures by open working or by mines.

2. The chief interbedded minerals from stratified rocks are: *coal*, chiefly from the Carboniferous, but also from the Oolitic, Cretaceous, and Tertiary systems ; *iron*, as magnetite, hæmatite, or clay carbonate (the latter from the coal measures), in stratified rocks, and also in the schists, aggregated or diffused ; *salt ;* and *gypsum.*

3. Other metallic ores are mostly found in fissures and faults mixed with non-metallic mineral matters, such as silica, carbonate of lime, fluor, barytes, etc., either crystalline or amorphous. The minerals may be native, or oxides, carbonates, sulphides, silicates, etc.

4. The amount and the nature of the lode depends apparently on the circumstances of its original formation, as well as on the nature of the rocky matrix. In *stockwerks* and *fahlbands* the ore is diffused through the rock, and sometimes masses occur as if they were interbedded.

5. Observation and experiment lead to the conclusion that most of these deposits are due to the long-continued action, often under great pressure, of heated water, which dissolves various substances out of the body of the rocks, conveys them to other localities, allows them to react on each other and produce fresh compounds; and then, as the result of these reactions, aided often by diminution of pressure or temperature, redeposits them.

6. By denudation minerals find their way into the drift, which thus serves as a guide to the lodes. In mining, the chief difficulties are ventilation, water, the tendency of the rocks to close together when the vein-stuff is removed, and the lifting of men and materials to the surface.

QUESTIONS.

1. Contrast a Yorkshire coal mine and a Cornish tin mine.
2. Under what circumstances does iron occur in the rocks?
3. Describe a typical *lode*.
4. Give an account of the manner in which the chief Cornish ores are distributed.
5. What is the probable reason why so many ores are found in fissures in metamorphic rocks?
6. What facts can be brought forward in proof of the aqueous formation of minerals?
7. Describe the manner in which a new country would be surveyed for mining purposes. Why are mining speculations so risky?
8. Why do mines tend to fill with water, and how is it disposed of?
9. What are the special dangers to be avoided in mines?
10. What metals are contained in the following minerals:—blende, pyrolusite, magnetite, cerussite, specular ore, ochre, galena, cassiterite, calamine, limonite?

CHAPTER XXXII.

SCENERY.

THE beauty of a landscape depends upon the shape or contour of the surface, the nature of the vegetation, the presence or absence of water, the state of the atmosphere and sky, and other minor conditions. In this connection, however, it is only proposed to regard the subject from the geological point of view, which is mainly concerned with the surface contours. The shape of the surface of any given region depends upon the character of the rocks as regards their proneness to weathering under the action of the various atmospheric agencies, and on the influences to which they have been subjected. Under the first head there is the texture and hardness of the strata. As a rule, hard rocks resist and soft rocks give way when exposed to denudation. For this reason we find clay lands generally flat and low, and slate regions frequently elevated. The clay, in addition to being soft, is uniform in character, and washes away easily everywhere, while slate is not so uniform, and is very fissile, and easily splits and breaks up, and thus tends to produce an irregular and rugged country. Joints in a rock greatly assist denudation, and all limestones, in addition to being denuded mechanically, are also readily dissolved, both on the surface and in the interior. The nature of the rock also affects the soil, and hence also the vegetation.

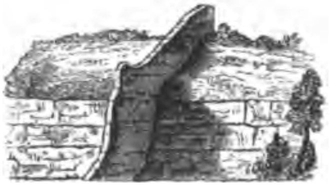

FIG. 298.—A dyke of igneous rock running through horizontal and softer rocks, and resisting denudation.

The lie of the rocks has an important influence. Stratified rocks are sometimes nearly or quite horizontal, and are then more likely to form a flat and monotonous country than when they dip at a high angle or when they are contorted, fractured, faulted, or broken into by eruptive rocks. It must not be supposed, however, that there is often any coincidence between the flexures and slope of the rocks and the contour of the surface. That entirely depends upon what has happened since. There are cases where the high ground coincides with the anticlinals and the low ground with the synclinals, but, as a rule, it is just the opposite. It must be remembered that the flexures were formed when the rocks affected were deeply buried under other strata, which have since been denuded away. Whether the folds were formed by lateral pressure or by upward thrusts, it is plain that the ridge of an anticlinal would be strained, and likely to crack and develop fissures parallel with its axis, while at the bottom of a synclinal the rock would be compressed, and made harder and more compact than before. Consequently, when the contorted strata become exposed to atmospheric denudation it is, as a rule, the synclinal troughs that resist, and the anticlinal ridges that give way. Hence, in a mountain region where the strata lie in a series of parallel folds, although it may occasionally happen that the high ground coincides with the anticlinals, yet, as a rule, it is the opposite, the strata which are geologically highest being found in the valleys, and those which are the lowest on the high ground. The fact that

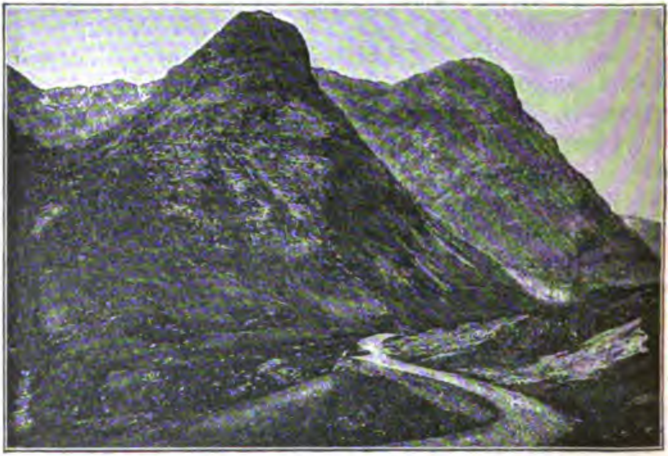

FIG. 299.—The Sisters of Glencoe. (Wilson.)

hills, as a rule, stand on synclinals is expressed by the well-known observation that strata "dip into the hill." But although the flexures do not make surface features of themselves, they almost invariably give rise to diversified scenery, inasmuch as they bring strata of various resisting powers to the surface. It may happen that the strata of a given area, instead of being crumpled up into a series of folds, may be lifted bodily up some hundreds or even thousands of feet. This would tend to form a comparatively level table-land, such as that which forms the elevated region between the Rocky Mountains and the Pacific coast-range. Or a huge boss of granite, which has intruded itself into a series of sedimentary rocks, may have its top laid bare, and form a table-land or elevated ridge.

Most mountain regions, however, are much more complex than the preceding cases, and seem to be the result of a series of disturbances. The Alps will serve as a type. The core of the system consists of schists and igneous rocks, upon which later Palæozoic and Secondary rocks were afterwards deposited, metamorphosed, elevated, and denuded. Submergence again followed, and Eocene rocks were laid down horizontally upon the range. Then a grand disturbance and upheaval occurred, during which the rocks, including the Eocene, were crumpled, inverted, metamorphosed, and intermixed in such a manner as to be in many cases quite unrecognizable. The effect of denudation since the last elevation has been to carve out the strata in such an irregular fashion that strata of any geological age may be found, indiscriminately, either at the bottom of a valley or at the summit of an aiguille.

The results of volcanic action may or may not be apparent to the sight. The sweeping conical form of an active or recently extinct volcano is very marked, and there are regions where these give a special character to the landscape—as, for example, the Eifel or Auvergne. From such comparatively perfect specimens there is every downward gradation. In the Alban Hills, near Rome, and in other Italian localities, placid circular lakes repose in the extinct craters of old volcanoes. The last portion of a volcano to disappear is often the solidified plug of lava which remained in the lower part of the crater, and which frequently resists denudation when all else has disappeared; and when this is obliterated, and the position of the volcano is quite blotted out, we still find evidence of its former presence in the sheets and dykes of lava and basalt which are associated with the other rocks.

In considering the building up of the land, it is necessary to continually recall the fact that elevating as well as denuding forces have been always in action; and the fact that Eocene rocks top some of the Alpine peaks, shows us that there has been enormous elevation even in geologically recent times. If these elevations had not occurred, atmospheric action alone would long ago have reduced all the land to a dead level covered with shallow water, so that it will be observed that while the first effect of subaerial denudation is to make the surface rugged and uneven, the final result is to reduce it to a level plane.

As practically all stratified rocks have been formed under water, it follows that any land surface composed of stratified rocks must once have been in the act of rising from the sea. As it rose, the sea would form a more or less complete "plain of marine denudation." This plain, owing to variations in its component rocks and in the rate of elevation, would probably vary considerably from a perfect level, and consequently the rain which fell upon it would from the very first gravitate towards the lowest parts, and find its way down definite channels to the sea. This would fix the position of the river valleys, and would practically determine the general features of the country. From this period the valleys would be deepened and widened according to the nature of the rocks, the slope, the rainfall, etc., as explained in the chapter on river action. The heads of the valleys would gradually wear themselves back into the high ground, converting a broad and gentle slope into a narrow ridge, and finally would begin to cut the ridge itself away, forming passes and gaps, and isolating craggy peaks or tabular and massive hills from each other. From these considerations it is evident that it is not quite correct to assume that the highest points are necessarily those which were the hardest and best calculated to resist denudation, as equally hard rocks lying in the courses of the rivers are cut into and worn away. The peaks owe their existence primarily to the fact that they were far removed from river action, and secondly to their superior resisting power. In a region where rocks of varying hardness lie one above the other with a gentle and uniform dip, a very characteristic feature in the scenery is formed by the escarpments of the harder rocks. The Chiltern Hills, for example, running north-east and south-west through Oxfordshire, and the North and South Downs are escarpments. It was once imagined that they were formed by the sea, though sea-cliffs are rarely confined for a long distance to the same stratum, but that theory of their origin is quite disproved by the fact that their bases do not maintain the same level as the foot of an old sea-cliff would. Most of these escarpments were probably started by a river cutting a valley somewhat in the line of strike, and so forming a cliff. This cliff, working backwards in the usual way under the influence of atmospheric denudation, has formed the escarpment. A more puzzling feature is the case of a river flowing through a gap cut through an escarpment at right angles. For example, the river Medway, in Kent, flows with a winding course over a piece of flat ground formed by the gault clay, and then goes to the sea through a valley which is five hundred feet below the top of the escarpment of the North Downs on each side of it. It is obvious, of course, that if a river were to be directed against an escarpment it would never excavate a valley through it, but would simply be dammed back by it, and diverted into another direction. The explanation lies in the fact that the rivers commenced flowing in the directions they flow at present before the surface features of the country were formed. The Medway began to flow when the great plain of marine denudation of the Weald was, perhaps, almost flat, and it has gradually cut its way downwards through the chalk, drawing at the same time through the gap enormous quantities of silt and mud derived from the other strata to the south. If this principle, viz. that the rivers have flowed approximately as at present since the last elevation of the land, is borne in mind, it will be found to explain most cases where rivers flow through hill ranges, even when, as in the case of the Blackwater and other rivers in the south of Ireland, they seem to go out of their proper course to do so.

Glacial action comes in as a disturbing element. When a country undergoing subaerial denudation is for a time buried under an ice-sheet, the ruggedness and inequalities are toned down, and now and then the drainage system is somewhat altered by the choking up and obliteration of portions of river valleys by boulder clay. This has been already alluded to, and the formation of lake basins by glacial action has been explained.

If the foregoing principles are applied to the explanation of the scenery of the British Isles, it becomes clear why the Scotch Highlands, Cumberland, and Wales are wild, hilly, and more or less barren. These regions are composed of slates, schists, and igneous rock, very much contorted, faulted, and intermixed. There is evidence that they have, in very remote times, been once or more levelled off by the sea, and that, in parts, strata thousands of feet in thickness have been removed. In these regions there is no connection at all between the lie of the strata and the surface contours. Among the rocks of the Carboniferous system, the millstone grit and the mountain limestone cause very marked features. The coarse rough slabs of the former cap many of the West Riding hills; and the scars of the latter shut in the dales, or rise above them on the flanks of the hills in Yorkshire and Derbyshire. The Oolitic, Liassic, and Chalk escarpments stretching in parallel lines one behind the other across the midland and eastern counties have also been described. The smooth, rounded, and waterless surface of the chalk downs is very marked and quite distinct.

The effect of the sea on coast scenery and outline has been fully described in treating of the sea as a denuding agent. Soils and their dependence upon the rocks from which they originate have also been discussed. Enough has been said to show that the character of our hills and valleys, lakes, sea-cliffs, and all the varieties of surface and outline which the land presents are easily explained when we consider, on the one hand, the nature of the rocks, and on the other hand the influences to which they have been subjected; and only those who are ignorant of these studies can doubt that such knowledge gives an additional interest and charm to natural scenery, whether it be a grand Alpine panorama or a Yorkshire dale.

SUMMARY.—1. Scenery, so far as geology is concerned, depends on—

(1) The varying physical properties of rocks.
(2) Their lie:—
  (*a*) Contorted and fractured rocks of varied character make an irregular hilly country.
  (*b*) Horizontal or gently sloping strata make long lines of low hills (escarpments).
  (*c*) Volcanic areas, if not excessively denuded, contain more or less symmetrical isolated hills, and often circular crater lakes.

2. River valleys, which are the key to the contour of a district, generally originated on an almost level plain of marine denudation, gradually forming escarpments, and often at the same time cutting a channel through them.

3. Atmospheric denudation is sometimes checked, and its effects largely obliterated by the occurrence of a "glacial period."

4. The outline of the coast depends on the nature and lie of the rocks, and the horizontal action of the sea, as explained in Chapter XI.

5. The nature of the soil, and to a large extent the flora and fauna of a country depend also on the rocks.

QUESTIONS.

1. What elements of a landscape depend on the geology of the district directly or indirectly?

2. Why does a slate differ from a clay district?

3. How, and to what extent, does the surface contour depend on the lie of the rocks?

4. Describe the origin of a table-land.

5. Describe the appearance of a recently extinct and a long extinct volcanic area.

6. What is the connection between the mountain system and the river system of a country?

7. What is the difference between a sea-cliff and an escarpment? Mention some escarpment hills in England.

8. What effect has the occurrence of a glacial epoch upon a country as regards its contour and scenery?

CHAPTER XXXIII.

THE ICE AGE, AND ITS CAUSE.

In the chapter describing the action of ice a full description has been given of those phenomena which place it beyond a doubt that many of those regions of the earth which now enjoy a temperate climate have been at some former period buried under an enormous sheet of ice. There is no other way of accounting for the perched blocks, boulders, *roches moutonnés*, and the various other circumstances which attract our attention in so many parts of the world. They are found both in the Old World and in the New, and in the southern hemisphere as well as the northern. The presence of a great ice-sheet implies an Arctic climate, and there has been much speculation as to how such an Arctic climate could have been brought about.

In considering this question it would be an advantage if we could have definite answers to two questions. The first is as to whether the Arctic conditions prevailed in Europe, Asia, and North America at the same time, or whether the Old World was glaciated at one period and North America at another. There is, at any rate, no reason whatever to suppose that the latter was the case, so we may take it for granted that the northern glaciation was caused by an extension of the Arctic conditions southward over a great portion of the north temperate zone. The second question is whether the southern hemisphere was glaciated at the same time as the northern. It is impossible to answer this question. If the northern and southern glaciations happened together it would point to a general cooling of the earth's temperature, while if they alternated it would suggest that the heat which one hemisphere lost was temporarily transferred to the other. This latter state of things is much more easy to account for than the former.

Another fact to take note of in attempting an explanation is the occurrence of alternate glacial and "interglacial" periods, *i.e.* periods of glacial conditions alternated with milder periods when the ice melted. No explanation can be considered satisfactory which does not take account of this.

There is one more point. Far away in the North, in the cliffs which bound the northern part of Baffin's Bay, fossil vegetation has been disclosed which could only have flourished in a comparatively warm climate. The occurrence, therefore, of a former genial climate within the Arctic circle has also to be explained.

The various explanations which have been brought forward may be classed as either geographical or astronomical. The only one of the former class which need be alluded to is that which was brought forward by Sir Charles Lyell in his "Principles of Geology." He pointed out that extreme conditions of climate could be brought about, according as all or most of the dry land was arranged near the equator or near the poles. If the land were accumulated towards the poles glacial conditions would be promoted, and if around the equator with open oceans in the North and South, the climates of the extreme North and South would be rendered much less rigorous than they are at present. This arrangement would, if needed, give us glacial epochs in the North and South contemporaneously; but the interglacial periods are difficult to account for, as we cannot suppose that the land would oscillate up and down several times to a sufficient extent. Moreover, there remains the fact that there is no evidence whatever that such extensive changes of land and water have ever occurred in geological times, and it is absolutely certain that they have not happened within such comparatively recent times as are demanded by the theory. The land, indeed, during the glacial epoch was in pretty much its present state.

There remains, therefore, only the astronomical theories. One theory is, that as the solar system travels through space it goes through hot and cold regions. But we get practically all our heat at present from the sun; the small amount received from the stars would not be missed. Consequently, if we were left with only the sun's heat we should be no colder than we are now, and therefore there could be no glacial epoch produced. It must therefore be due to some modification of the relations between the sun and the earth. The only changes we can imagine are, either that the sun's heat has in past times varied in intensity, which is extremely unlikely and unsupported by any evidence, or that the amount of heat received by the northern and southern hemispheres of the earth has varied at different epochs. This latter supposition appears to be the true one, and astronomers are able to explain how the matter can be brought about. This has been done by Dr. Croll and others, and recently in a more exact and explicit manner by Sir Robert Ball, the Royal Astronomer of Ireland. This astronomical explanation of the Glacial period we will now proceed to set forth.

Before considering how the heat received from the sun varies, we must consider what the amount of that heat is, and what would be the consequences of its withdrawal. The thermometer in ordinary use, by which we measure the intensity of heat, is that which was first constructed by Fahrenheit, and is named after him. The heat of boiling water is on it marked 212°, freezing water or melting ice 32°; and 32° below that point we reach 0°, or the zero point of the scale. It might be supposed that this zero denoted the absence of all heat, and that it represents the temperature which would prevail in the earth if the sun's heat were withdrawn. This, however, is by no means the case. Very much lower temperatures than this are actually met with in the Arctic regions, and still lower points have been obtained by artificial methods. These experiences and other considerations point to the fact that the absolute zero of temperature, the cold of empty space, the temperature which would prevail on the earth's surface if the sun were annihilated, would be approximately 300° below the zero of the Fahrenheit thermometer. Looked at from this point of view the range of summer and winter temperatures is much less than it appears. Take the case of a country with a mean winter temperature of 40° F. and a mean summer temperature of 60° F. It might seem from these figures that the summer was half as hot again as the winter. But if we reckon from the absolute zero point, the figures then become 340° and 360° where the difference is relatively insignificant, the winter only having one-eighteenth less heat than the summer. If a loss of one-eighteenth of the heat will transform summer into winter, it is obvious that a comparatively small variation in the relative amount of heat received by any given part of the earth's surface would very seriously affect the climate, and this should be carefully borne in mind.

The earth moves round the sun in an orbit which, though elliptical, approximates very nearly to a circle. Other planets, some nearer the sun than the earth, others more remote, do the same. These planets are attracted by, and attract the sun, and they also attract one another, with a force which depends on the total mass of the attracting bodies and the distance between them. Fixing our attention on the earth, we note that Venus and Jupiter are the two planets which, on account of their size and the proximity of their orbits to that of the earth, will exercise by far the greatest influence, though compared with the sun their attraction, even under the most favourable circumstances, is extremely small. These planets will, each of them, pull the earth forward in its orbit, retard it, or pull it sideways, according to their position with reference to it. Sometimes both will act in unison, sometimes they will oppose each other, generally an intermediate state of things will exist. Similarly, but in a less degree, all the other planets do their share. The consequence of this is that the earth, instead of going smoothly and regularly on its course round the sun, is subject to various perturbations. The axis is subject to a slow rotary motion, the elliptical orbit becomes less or more elliptical, and the major axis of the ellipse, though it never varies in length, varies in position. These disturbances, however, never go beyond a certain maximum, so that the stability of the solar system is in no danger of being upset, but they have very important consequences on the earth's climate.

Before proceeding, there are one or two points which should be clearly grasped. The first is, that the *total heat received by the earth in a given time* depends on its distance from the sun, and on nothing else. The second requires a little consideration of the earth's annual path round the sun. The path is an ellipse, and the sun is in one of the foci. Consequently the earth is nearer the sun at one time of the year than it is at another. Let A C B D (Fig. 300) represent the earth's orbit. It is clear that the earth, in journeying from D through A to C is nearer the sun (S) than when journeying from C through B to D.

Consequently in *the same time* it receives more heat in the first section than in the second. But in the former case it is not exposed to the greater heat for so long a time, because the distance is less, and also because under the greater attraction of the sun it travels faster. This shortening of the time while the earth travels through the hotter section of its orbit exactly counterbalances the greater heat, so that precisely the same total amount of heat is received by the earth while travelling through the one portion as the other. This principle may be extended still further. If the orbit be divided into any two parts by a straight line drawn through the sun, as E S F, then the earth receives from the sun as much heat while travelling through F D A E as through E C B F.

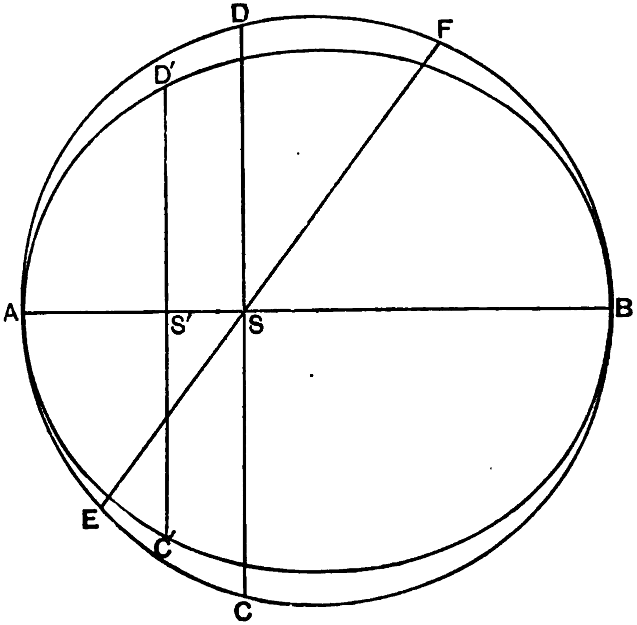

FIG. 300.

We must now consider the distribution in time of the heat which falls on the northern and southern hemispheres respectively. If the earth's axis were at right angles to the plane of the orbit, each hemisphere would get an equal share of every day's heat; but as the axis is inclined 23½° from the perpendicular, this is by no means the case. Dividing the year into two approximately equal periods, which we will call summer and winter respectively, we find that, during the summer of the northern hemisphere, that half of the globe is getting nearly twice as much heat as the southern hemisphere, while during the northern winter the conditions are reversed, the northern half getting little more than half as much as the southern. Each hemisphere therefore gets in the year just as much heat as the other. If we represent the total amount of heat received by the whole globe by 200, then each hemisphere receives 100, 63 per cent. being received in the summer of that hemisphere, and the remaining 37 in the winter.

The earth's orbit is divided into two portions by the equinoctial points. These points represent the positions of the earth when neither the one pole nor the other is turned either towards or away from the sun; a line joining the centres of the sun and earth is at right angles to the earth's axis. They are the points where a plane parallel to the plane of the earth's equator and passing through the centre of the sun would cut the orbit. The position of these points depends, therefore, on the direction of the axis of the earth; and it is evident that if this direction should alter, the earth would have to shift into another position before the above state of things could exist, *i.e.* the equinoctial points would shift their position on the orbit. This is exactly what is known to happen. The north end of the earth's axis produced is slowly describing a circle in the heavens, thus causing the equinoctial points to travel all round the orbit. The consequence of this is that they are sometimes at the ends, A B, of the major axis of the elliptical orbit, and sometimes at the extremities, C D, of a line at right angles to the major axis. Let us take the first case when the line of the equinoxes corresponds with the major axis. The equinoctial points represent the position of the earth at spring and autumn, consequently, in travelling through one section, say B F D A, the northern hemisphere will have its summer, and in travelling through A E C B its winter. In this case the one season will evidently be just as long as the other, and the heat of summer will be spread out over exactly half the year. But suppose that the equinoxes are at C and D. Then the northern hemisphere would have its summer while traversing quickly the section D A E C, and its winter while travelling more slowly through C B F D. The $\frac{63}{200}$ of the total heat received by the earth in a year will be received by the northern hemisphere while traversing quickly the short section D A E C, while the $\frac{37}{200}$ will be spread over the longer period which it occupies in traversing C B F D. Consequently such a position of the equinoxes is favourable to the northern hemisphere having a short but hot summer, and a long, and therefore cold, winter. It should be noticed, also, that it is the reverse with the southern hemisphere, which receives its $\frac{63}{200}$ while traversing slowly the larger section C B F D, and its $\frac{37}{200}$ while travelling quickly over D A E C. The southern hemisphere, therefore, at this period, would have a long, but relatively cool summer, and a short but mild winter.

The change in shape of the elliptical orbit now requires attention. The major axis never alters, but the minor axis, that is the width of the ellipse, slowly shortens till it reaches a minimum, and then lengthens to its maximum, and so on. The effect of a flattening of the ellipse is that the foci get further and further apart, each focus getting nearer the end of the major axis. This brings it to pass that when the earth is at that end of the ellipse which is nearest the sun, *i.e.* in "perihelion," when the minor axis is at or near its minimum, it moves with still more accelerated velocity. The summer period of the northern hemisphere is then reduced to its minimum. It has to traverse the short section, D′ A C′, at accelerated speed, and the long one, C′ B D′, very slowly, on account of its increased distance from the sun. We have now the most favourable position for an intensely hot northern summer, and a long and very cold northern winter. In the diagram the eccentricity is enormously exaggerated. The shortest summer which could possibly occur under the conditions prescribed would be 166 days long, while the winter would be 199. During such a long cold winter more ice would be formed than could melt during the summer; the ice would consequently continually increase until, in the course of time, more favourable conditions were brought about by the shifting of the equinoxes.

There is still another periodic change to notice, viz. the slow rotation of the elliptical orbit, or the "revolution of the apsides." This movement takes place in the opposite direction to the movement, or "precession," of the equinoxes, and, therefore, practically has the effect of accelerating this movement. The major axis of the ellipse moves round in one direction in a period of 109,830 years, while the precession of the equinoxes takes place in the opposite direction in 25,868 years. In other words, in one year the extremities of the major axis travel in one direction $\frac{1}{109830}$ of the circuit, while the equinoxes travel $\frac{1}{25868}$ in the other direction. They thus approach each other at the rate of $\frac{1}{109830} + \frac{1}{25868} = \frac{1}{20937}$ of the circuit in one year, and, consequently, in 20,937 years they would occupy again exactly the same relative positions. Therefore, if the northern hemisphere were at any particular period having its summer when nearest to the sun ("perihelion"), in 20,937 years it would again have worked round into a similar position; while at the intermediate period, 10,500 years from either, the northern hemisphere would have a long summer and a short winter. These periodic changes have been continually taking place; but the long northern winter only becomes long and severe enough to produce glacial conditions when the eccentricity of the orbit is somewhere near its maximum. As this change of eccentricity is of very long period, several glacial epochs might be produced in succession before the minor axis became sufficiently elongated to mitigate their severity.

It may be asked why a short and intensely hot summer and a long cold winter should be a more favourable arrangement for producing glacial conditions than when the seasons are less extreme, seeing that the amount of heat received by the hemisphere during summer and during winter respectively are the same in the one case as in the other. Why should not the concentrated heat of the summer melt all the ice accumulated in the winter? The following reasons have been given. The white snow and ice would reflect a large proportion of the sun's rays back into space, so that, as far as their terrestrial effects are concerned, they would be lost. The abundant evaporation would fill the cold air with aqueous vapour, which would condense into cloud and fog and cut off the sun's rays from the earth. Again, Mr. Croll has pointed out, though Sir Robert Ball denies it, that the trade winds would always be stronger on that side of the equator which was nearest to the colder hemisphere, and this would cause the warm equatorial currents to be diverted toward the milder hemisphere, and, therefore, away from the colder. At the present time, for example, the southern hemisphere is suffering modified and partial glacial conditions, its winter being seven days longer than its summer, and the consequence is that the south-east trade wind is stronger than the north-east, and so causes powerful warm currents to flow to the northward along the western side of each of the great oceans. Similarly we conclude that, if the northern hemisphere were exposed to glacial conditions, the set of the currents would be southward, and the cold would be to that extent intensified.

The points demanding special attention in this astronomical theory of the glacial epochs are, firstly, that, whether the summers and winters are short or long, the relative amounts of heat obtained by each hemisphere at each season are fixed and unalterable, viz. of the total received by the whole globe in the year, each hemisphere receives in the summer $\frac{63}{200}$, and in the winter $\frac{37}{200}$; secondly, that, owing to the combined effect of precession and the revolution of the apsides, it comes to pass that in the course of every twenty-one thousand years the equinoctial points occupy every possible position in the orbit, and that, therefore, once in every period of that length the earth is in its most favourable position to produce a short northern summer and a long northern winter. Ten thousand five hundred years after this time the conditions will be reversed, and the northern hemisphere will have a long summer and a short winter. Thirdly, the difference between summer and winter will not, under ordinary circumstances, be sufficiently great to produce glaciation in what are now the cool temperate regions, except when the eccentricity of the earth's orbit reaches, or nearly reaches, its maximum. As the change of eccentricity is of very long period as compared with the other changes in the orbit, it follows that the eccentricity will be sufficiently near its maximum for a period of time long enough to allow for several glacial periods. Let us suppose, for instance, that for a period of one hundred thousand years the eccentricity is sufficient for glacial purposes. Then, as the northern hemisphere has a glacial period every twenty-one thousand years, there will be practically time for five glacial periods in succession, separated by mild "interglacial" periods. During this long period the southern hemisphere will have glacial periods while the northern is enjoying mild intervals, and *vice versâ.* Then will follow a long period during which the eccentricity will be too little to produce glacial conditions, and this, again, will gradually change into another period of maximum eccentricity. If this is the true explanation of glacial epochs, it is evident that the glacial epoch which left the boulders, till, *roches moutonnés*, etc., was not the only one, but that these glacial conditions must have been recurring through all the geological periods.

The astronomical explanation of glacial periods requires, firstly, that several glacial periods shall follow one another in geologically rapid succession, and that they shall be separated by comparatively mild epochs. This is quite borne out of the existing glacial phenomena. It also requires, secondly, that the glaciation should be contemporaneous throughout one hemisphere; that is, that Northern Europe, Asia, and North America should all have been under the same conditions at the same time. There is nothing known to disprove this, though it cannot be positively proved. Thirdly, the theory requires us to believe that the glacial period of one hemisphere corresponded with the interglacial or mild period of the other. This cannot yet be absolutely proved, though Sir R. Ball believes that certain phenomena of plant-distribution are best explained on that supposition. Fourthly, we must believe that throughout all geological time at certain periods glacial conditions have prevailed. Whether traces of these far-off glacial periods can be still discovered is doubtful, though there are here and there, in the series of stratified rocks, deposits which may possibly have such an origin. It should, however, be remembered that most of the glacial *débris* would become quite unrecognizable as such if carried away and redeposited by aqueous action. The bed of glacial clay full of scratched stones, one of the most characteristic and readily recognized glacial deposits, would be quite altered if its fine clay were washed away and deposited as a mud-bank at the mouth of a river; and its scratched and smoothed stones would soon lose all traces of their origin after being rolled about as shingle on a sea-beach. It is therefore not improbable that some of the numerous shales and clays, or beds of pebbles and conglomerate which recur so often in the geological series, originated in this manner. It is just possible that a careful examination and comparison of the strata in the equatorial regions, which have always been free from ice, and of those in the temperate regions might bring to light some points of difference which would throw light on this interesting question.

SUMMARY.—In connection with any explanation of glacial epochs, it would be a great advantage if, from observation, we could give definite answers to the following two questions:—

1. Was the European Ice age contemporaneous with the North American?
2. Was the northern hemisphere glaciated at the same time as the southern?

The theory should also explain the occurrence of—

1. Interglacial periods.
2. Warm temperate conditions within the Arctic circle.

Explanations offered—

1. Lyell's geographical theory.
2. Astronomical theories.
    - (*a*) Cold and warm regions in space.
    - (*b*) Alteration in the relations of sun and earth, bringing about a different distribution of a constant annual supply of heat.

Theory 2 (*b*), as developed by Dr. Croll and extended by Sir Robert Ball, seems the most probable. By the action of the sun and planets upon the earth in constantly varying positions, certain periodic changes are brought about, viz.—

1. Precession of the equinoxes.
2. Variation in eccentricity of the orbit.
3. Revolution of the apsides.

1 and 3 cause the winter of either hemisphere to be excessively long once in 21,000 years; and when the eccentricity is at or near its maximum, ice ages become possible.

QUESTIONS.

1. Enumerate the phenomena which have to be accounted for in any glacial theory.

2. Discuss Lyell's geographical explanation.

3. What is the objection to the idea that ice ages have been caused by the solar system passing at times through cold parts of the universe?

4. What percentage of the total annual amount of heat received by the earth falls (*a*) upon the whole globe during the northern winter, (*b*) upon the northern hemisphere at the same period?

5. What is the relative amount of heat in two equal quantities of water, one at 40° F. and the other at 60° F.?

6. Explain, with a diagram, what is meant by (*a*) ***precession***, (*b*) ***variation in eccentricity***, (*c*) ***revolution of apsides.***

7. What would be the character of the northern seasons when mid-winter occurs in perihelion?

8. How often does the condition in 7 occur, and why?

9. How, on this astronomical theory, are interglacial periods explained?

10. What evidence is there that series of ice ages have happened in past geological times?

EXAMINATION PAPERS.

1892.

Advanced Examination.

INSTRUCTIONS.

Read the General Instructions.
You are permitted to attempt *five* questions only.
The value attached to each question is the same.

21. Define the terms *fan-structure*, *head*, *holocrystalline*, *thrust-plane*, *vitreous*.

22. Describe some fossil hydrocarbons, other than coal.

23. By what processes are fossils sometimes dissolved out of clays?

24. How do you account for the presence of Arctic plants on mountains far south of the Arctic regions?

25. Describe the contemporaneous igneous rocks in the Devonian and Old Red Sandstone, *or* in the Carboniferous strata of Britain.

26. In what parts of Europe do extinct Volcanic Cones occur? How do we know them to be volcanic?

27. Give a brief description of the Permian *or* of the Purbeck strata. Mention some of the more important fossils, and describe the conditions under which the beds were formed.

28. What is meant by the terms *Acidic* and *Basic*, as applied to igneous rocks? Describe two examples of each.

Honours Examination.

INSTRUCTIONS.

Read the General Instructions.
You are permitted to attempt *five* questions only.
The value attached to each question is the same.

41. What do we know of the order in which minerals have been developed in igneous rocks? Give examples.

42. Describe *Loess*. Mention some area in which large deposits of this occur, and explain their origin.

43. Describe the main subdivisions under which the genus *Ammonites* has been arranged. Show the geological significance of this classification.

44. Describe the chief minerals of the *Pyroxene Group*; state of what rocks they are essential constituents, and note the effect of weathering and metamorphism upon these minerals.

45. Describe the stratigraphical and palæontological characters of the lowest Cretaceous and the highest Jurassic strata of N.W. Europe. Compare them with strata of corresponding age in other parts of the Continent.

46. Explain the formation of Deltas, and compare in this respect some of the European rivers of the Atlantic coast with those which enter the Mediterranean.

47. Give the characters of *Olenus*, *Olenellus*, *Paradoxides*. Explain the importance of these genera in the classification of strata.

1893.

Advanced Examination.

INSTRUCTIONS.

Read the General Instructions.
You are permitted to attempt *five* questions only.
The value attached to each question is the same.

21. What is meant by the term *Interglacial?*

22. What are *Zeolites?* In what rocks are they found?

23. Mention three animals or plants, now characteristic of colder regions, but found fossil in Britain.

24. Describe the formation of *Gneiss* by the alteration of Igneous masses.

25. Explain what is meant by the term *Passage-Beds*. Give an example.

26. Explain the terms *Apatite*, *Dolerite*, *Felsite*, *Kaolin*, *Lydian Stone*.

27. What is meant by the term *Ordovician?* Enumerate the leading divisions of the system.

28. Of what rocks do Sponges form important constituents?

Honours Examination.

INSTRUCTIONS.

Read the General Instructions.
You are permitted to attempt *five* questions only.
The value attached to each question is the same.

41. State the evidence for and against the theory of the excavation of Lake-Basins by ice-action.

42. What are *Radiolaria?* Mention some rocks, and their geological age, in which these occur; and compare such strata with similar Recent Deposits.

43. What has been done, in Britain and on the Continent, towards working out the zonal distribution of the Carboniferous Flora?

44. Describe the structure and the component rocks of *one* of the following districts:—(*a*) Malvern Hills; (*b*) Southern Uplands of Scotland; (*c*) Donegal.

45. Have we any evidence in the British Islands of changes in the relative level of land and sea within historic times? If so, describe the districts in which such evidence has been found.

46. Describe the chief ores found in Cornwall, with especial reference to their association and their relations to the surrounding rocks.

47. Saline waters are sometimes encountered in deep borings which do not touch the Saliferous New Red Rocks. Describe some instances, and explain the probable origin of the Saline Water.

48. Describe one of the Chalk areas of Britain; its structure, component beds, and physical geography, and its relation to water at the surface and underground.

CLASSIFICATION OF THE FOSSILS

REFERRED TO IN THE PRECEDING PAGES.

(Names of species in parentheses.)

I. ANIMALS.

1. PROTOZOA.

Foraminiferæ.—Eozoon; Globigerina, Nummulites, Rotalina, Spiroculina.
Radiolaria.

2. CŒLENTERATA.

Sponges.—Caryophyllia, Parasmilia, Protospongia, Siphonia (costata, pyriformis), Ventriculites.
Corals.—Clisiophyllum, Cyathophyllum, Favosites (cervicornis, Gothlandica), Halysites, Heliolites, Isastræa, Lithostrotion, Omphyma, Parasmilia, Petraia, Syringopora, Thecosmilia.
Graptolites.—Didymograpsus, Diplograpsus.

3. ECHINODERMATA.

Asteroidea.—Ophiolepis, Palæaster, Protaster.
Echinoidea.—Ananchytes, Cidaris, Clypæus (Plotii), Cyphosoma, Galerites (albogalerus), Holaster, Marsupites, Micraster (coranguinum).
Crinoidea.—Actinocrinus, Apiocrinus, Cyathocrinus, Dendrocrinus, Pentacrinus (Briareus), Taxocrinus.
Cystidea.

4. ANNULOSA.

Serpulæ.

5. ARTICULATA.

Crustacea.—Trilobites:—Agnostus, Angelina, Asaphus, Bronteus (flabellifer), Calymene (Blumenbachii), Encrinurus, Homalonotus (delphinocephalus), Illænus, Ogygia (Buchii), Olenus, Paradoxides, Phacops (caudatus), Phillipsia. Cypris, Estheria (minuta). Eryon, Eurypterus, Pterygotus. Glyphæa, Hymenocaris.
Spiders.
Insects (various).

6. MOLLUSCA.

Polyzoa.
Brachiopoda.—Atrypa, Chonetes, Discina, Lingulella, Orthis (striatula), Pentamerus (Knightii, oblongus), Productus (giganteus, horridus, punctatus), Rhynchonella (pugna), Spirifera (alata, princeps, speciosa), Stringocephalus, Strophomena (depressa, rugosa), Terebratula (carnea, grandis, sella, striata), Uncites.

Lamellibranchiata.—Anthracosia, Astarte (borealis), Avicula (contorta, cygnipes), Aviculopecten, Cardinia, Cardita (planicosta), Cardium (Grœnlandicum), Chama, Corbula, Cyprina (Islandica), Cyrena, Cythera, Exogyra (sinuata), Gervillia, Gryphæa, Hippurites, Inoceramus (concentricus, sulcatus), Isocardia, Lima, Mactra, Megalodon, Mitra, Modiola, Modiolopsis, Nucula, Oliva, Ostræa (flabelloides, bellovacina), Palæarca, Panopæa, Pecten (equivalvus, orbicularis, peregrinus, varius), Perna (Mulleti), Petunculus, Pholadomya, Posidonomya, Pterinæa, Rostellaria, Scalaria (Grœnlandica), Spondylus, Teredo, Trigonia (clavellata), Unio.

Gasteropoda.—Bellerophon, Cerithium (giganteum, Portlandicum), Conus, Cypræa, Euomphalus, Fusus (contrarius), Helix, Limnæa, Littorina, Melanopsis, Murchisonia, Paludina, Phasianella, Planorbis, Pleurotoma, Pleurotomaria, Pupa, Voluta (Lamberti, Solandri).

Cephalopoda.—Ammonites (bifrons, communis; Deshayesii, giganteus, heterophyllus, Humphresianus, Jason, Mantelli, Parkinsoni, rothomagensis, varians), Ancyloceras, Baculites, Ceratites, Crioceras, Hamites, Orthoceras, Scaphites, Turrilites. Belemnites, Belemnitella. Clymenia, Nautilus. Goniatites.

Pteropoda.

Heteropoda.

7. VERTEBRATA.

Fishes.—(i.) Elasmobranchii: Acrodus, Ceratodus, Hybodus, Ptychodus.
(ii.) Ganoidei: Cephalaspis, Dapedius, Glyptolepis, Holoptychius, Lepidotus, Osteolepis, Palæoniscus, Platysomus, Pteraspis, Scaphaspis.
(iii.) Teleostei: Beryx.

Amphibia.—Labyrinthodonts.

Reptilia.—Atlantosaurus, Brontosaurus, Cetiosaurus, Hylæosaurus, Iguanodon, Ichthyosaurus, Megalosaurus, Mososaurus, Plesiosaurus, Pliosaurus, Protosaurus, Pterodactyl, Rhamphorhynchus, Rhynchosaurus, Staganolepis, Teleosaurus, Telerpeton, Tortoise, Turtle, Snakes.

Birds.—Apteryx, Archæopteryx, Odontopteryx, Hesperornis, Macrornis, and recent genera.

Mammals.—Marsupials:—Amphitherium, Dromatherium, Microlestes, Phascalotherium, Stereognathus, Anoplotherium, Bos (primigenius), Cervus, Dinotherium, Elephas (antiquus, meridionalis, primigenius), Equus, Felis (spelæa), Gyptodon, Helladotherium, Hipparion, Hyæna (spelæa), Mastodon, Megatherium, Palæotherium, Rhinoceros.

II. PLANTS.

1. CRYPTOGAMS.

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Ferns:—Neuropteris, Pecopteris, Sphenopteris, Palæopteris. Lepidodendron, Sigillaria (with stigmaria).

2. PHANEROGAMS.

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